Overview of ITER Vacuum Systems

D A. Rasmussen[2], R J H. Pearce[1], A. Antipenkov[1], JL. Bersier[1], B. Boussier[1], S. Bryan[1], M. Dremel[1], S Hughes[1], R Kersevan[1], C. Mayaux[1], L. Worth[1], M. Wykes[1], L R. Baylor[2], R C. Duckworth[2], W L. Gardner [2], M. Hechler [2], S J. Meitner[2], R. Peters[2], W. Owens[2], M. Williams[2], R. Laesser [3], G. Piazza[3], S Papastergiou[3],C. Day[4], J-M Poncet[5]

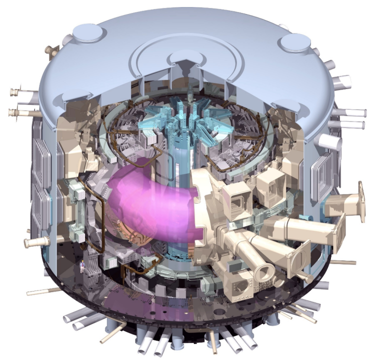
[1]ITER Organisation, Route de Vinon, CS 90 046, 13067 Saint-Paul-lez-Durance Cedex, France

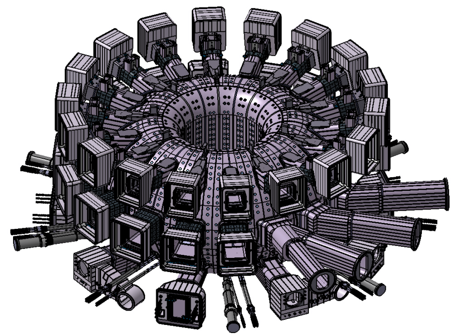
[2]US ITER Project Office Oak Ridge National Laboratory, Oak Ridge, TN, USA

[3]Fusion for Energy, Josef Pla, 2, Torres Diagonal Litoral B3, 08019 Barcelona

[4]Karlsruhe Institute for Technology, Institute for Technical Physics, Karlsruhe, Germany

[5]CEA, 17 rue des Martyrs, 38054 Grenoble, Cedex 9 France

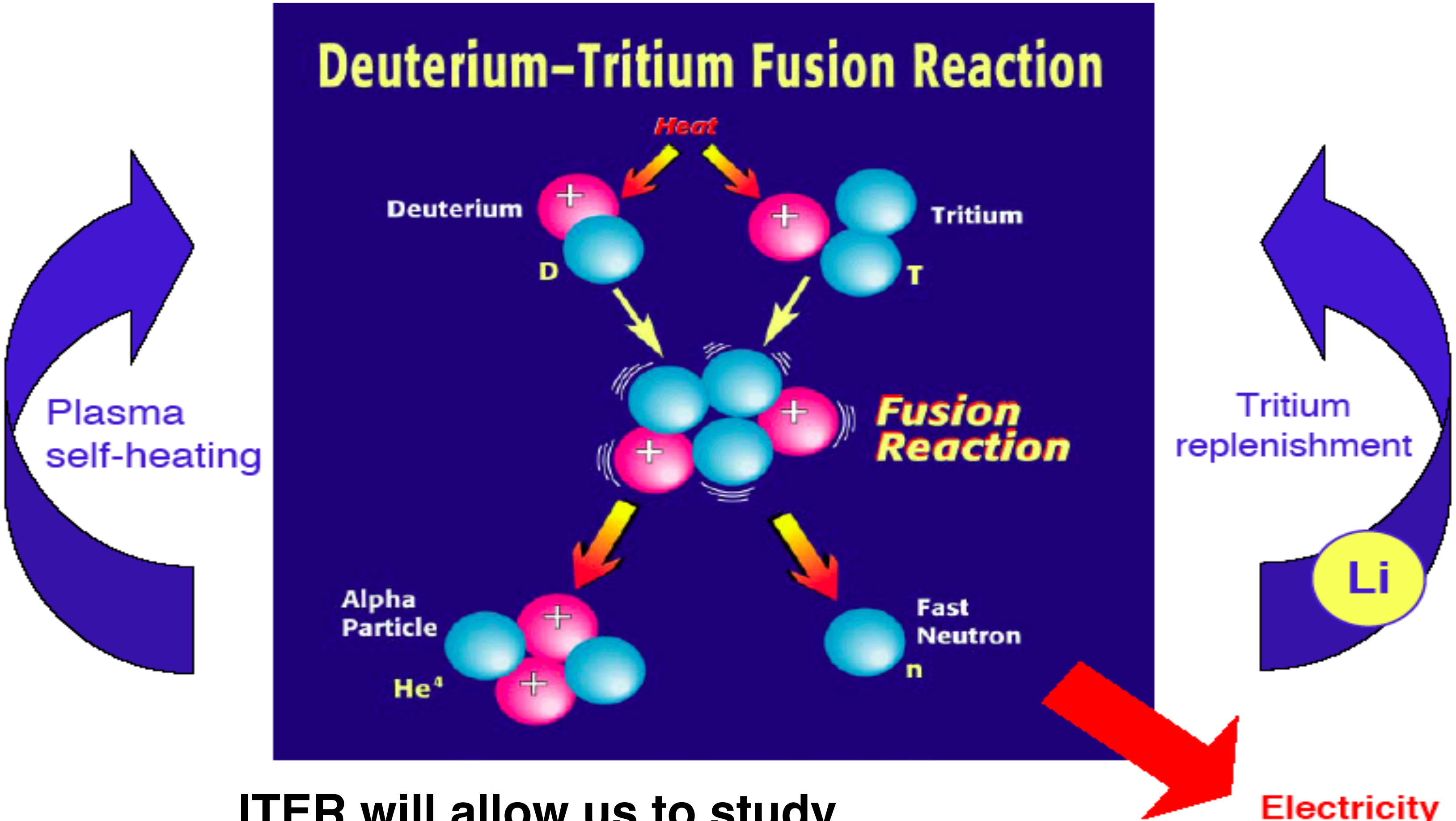




Third Workshop on Operation of Large Vacuum Systems

July 11-14, 2011
Oak Ridge, Tennessee

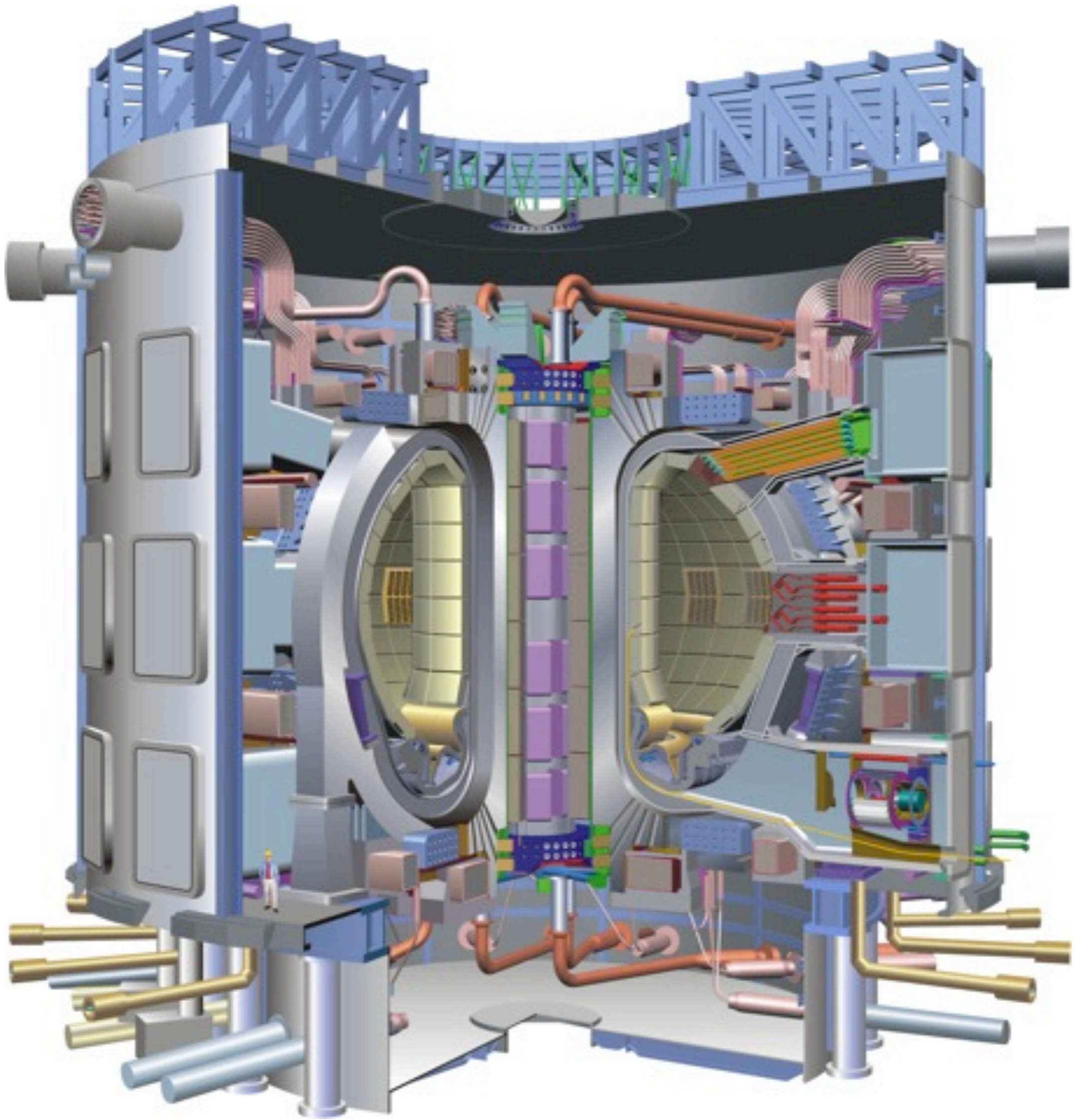
Fusion Energy Production Requires a Sustained Burning Plasma with a Closed Cycle



ITER will allow us to study

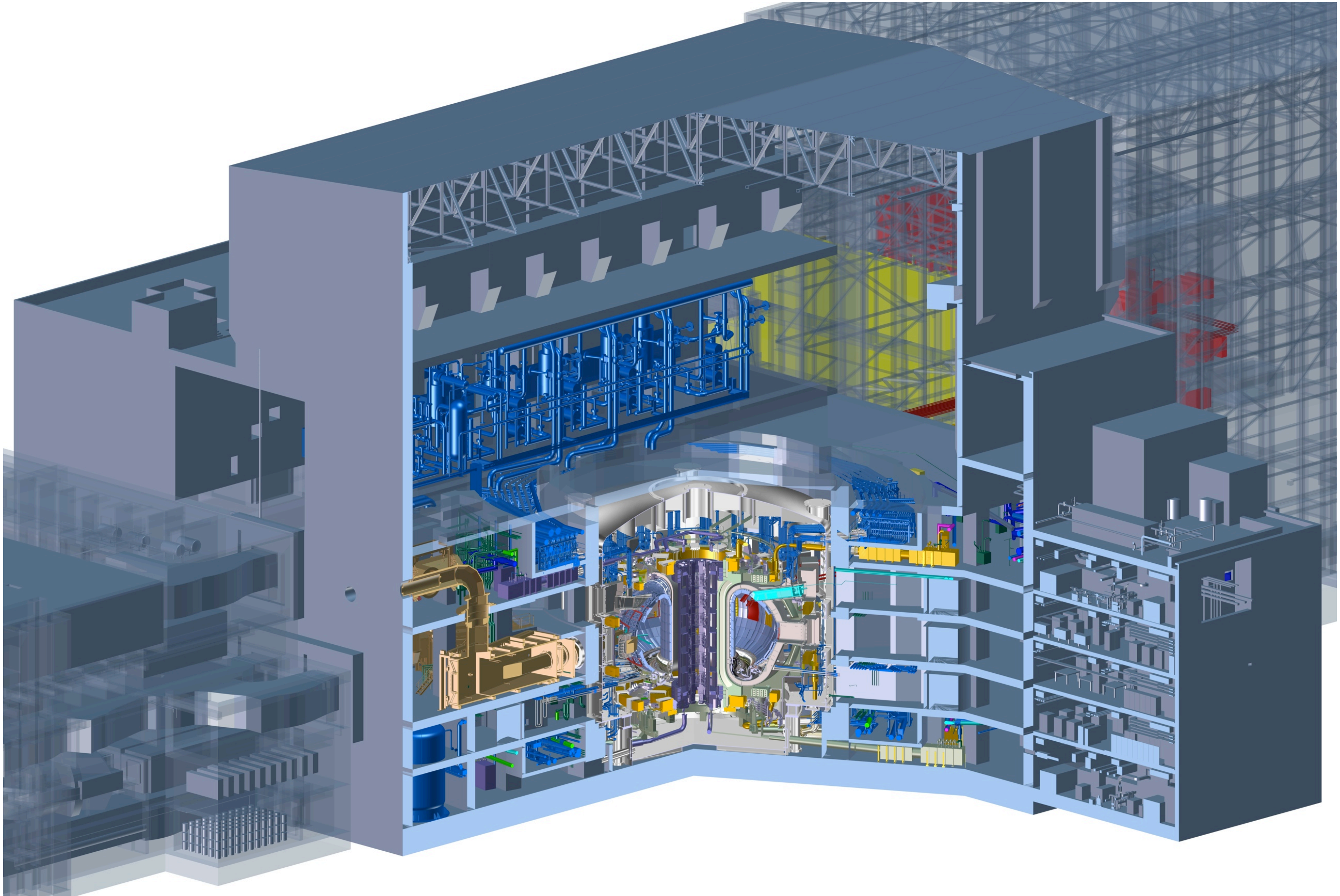
- He plasma self heating and control
- neutron damage/capture processes
- tritium recycling
- Efficient Pumping of Light Gases

ITER Design Features and Performance Goals

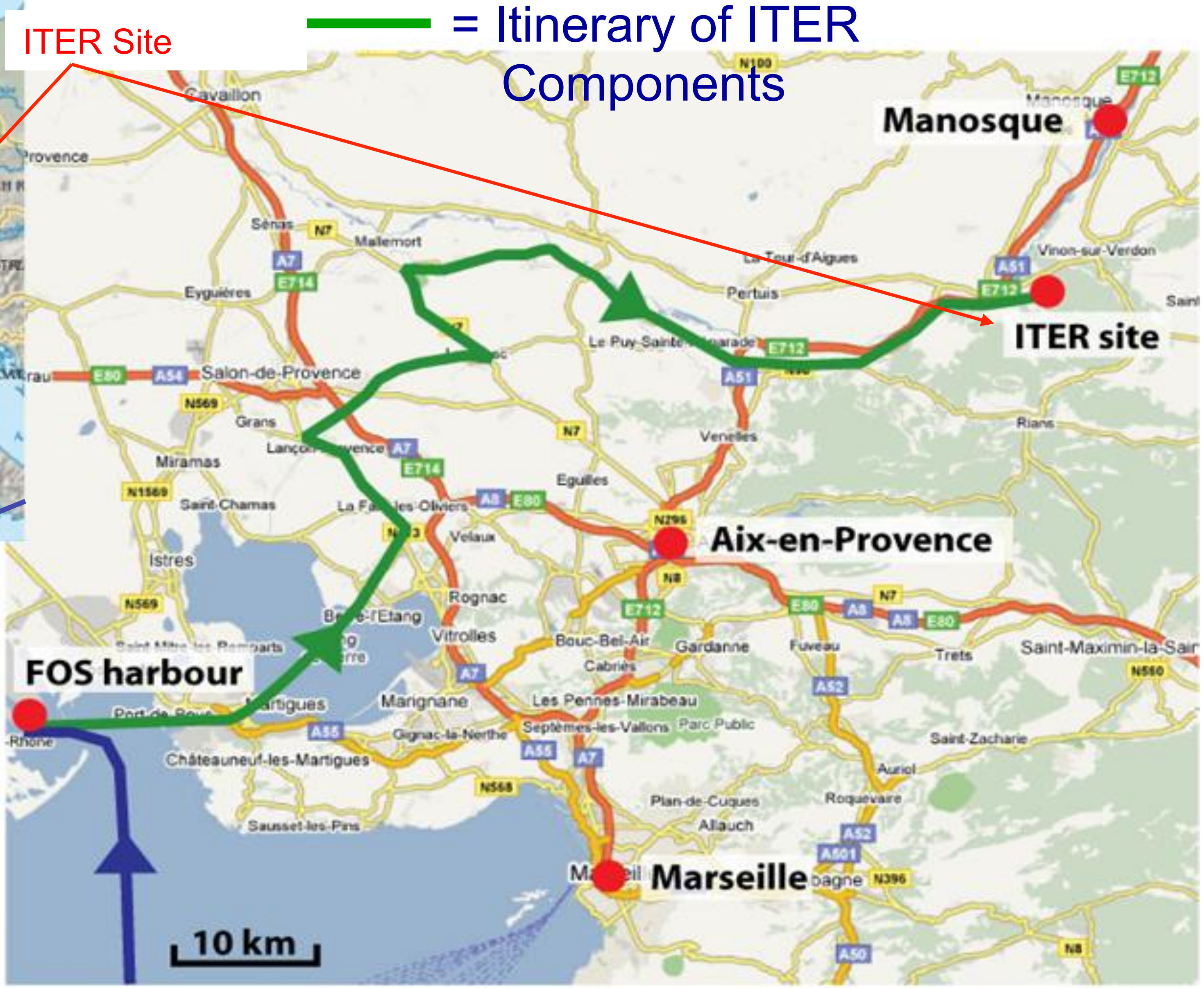


- ITER will be the worlds largest fusion experiment and first to generate a burning plasma
- Allows the study of <u>physics</u> and <u>technology</u> for this regime
- Fusion power generation goals:
  500 MWs for 7 minutes; Q~10
  350 MW for 1 hour; Q~5
- Plasma heating systems are need to initiate, heat and control ITER.
- 10 MAs of plasma current
  70 MWs wave and beam systems
- Plasma facing tiles require advanced materials and efficient cooling

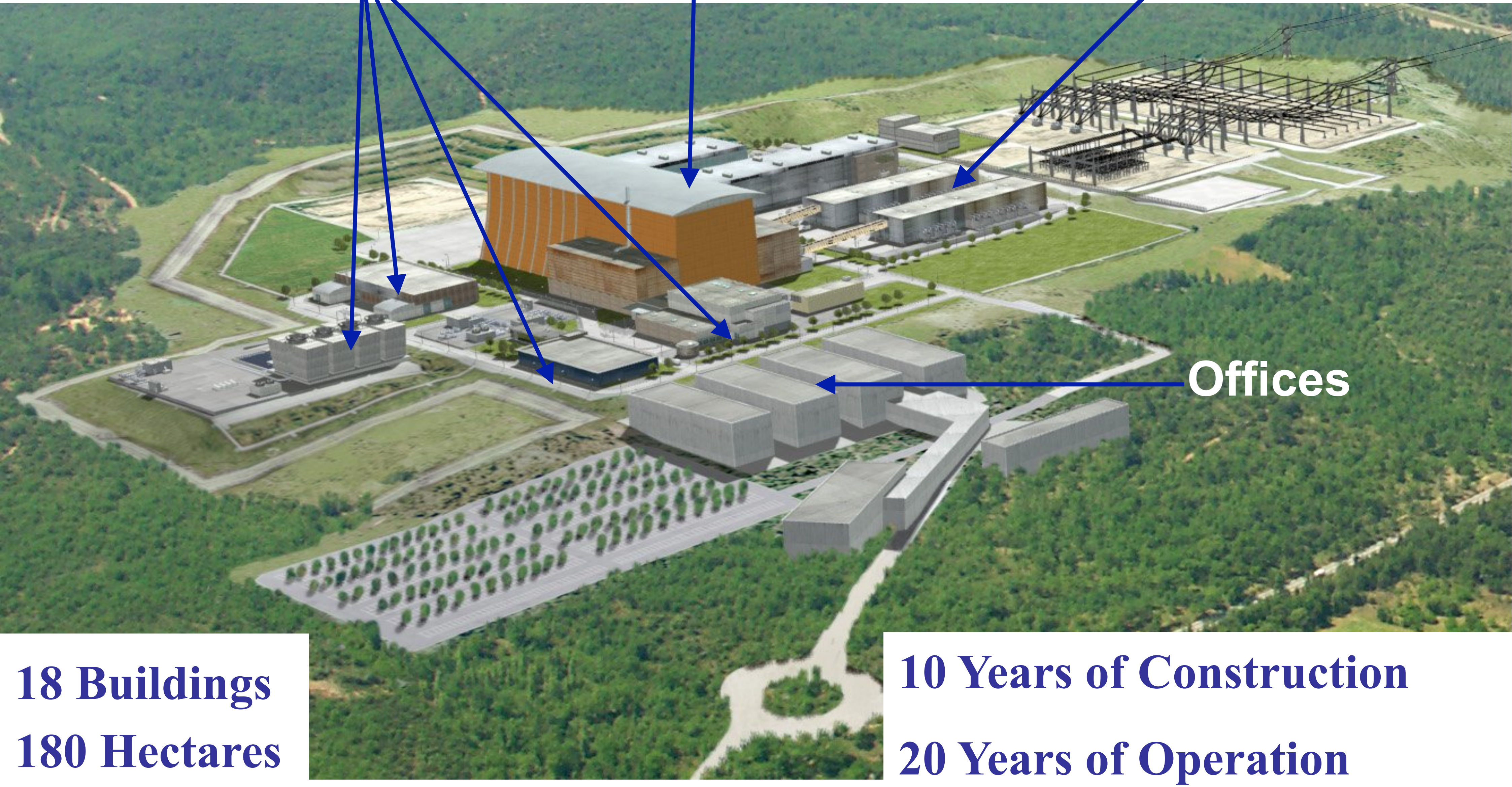
ITER Tokamak Building



ITER site is Cadarache in South of France



The ITER Complex



18 Buildings

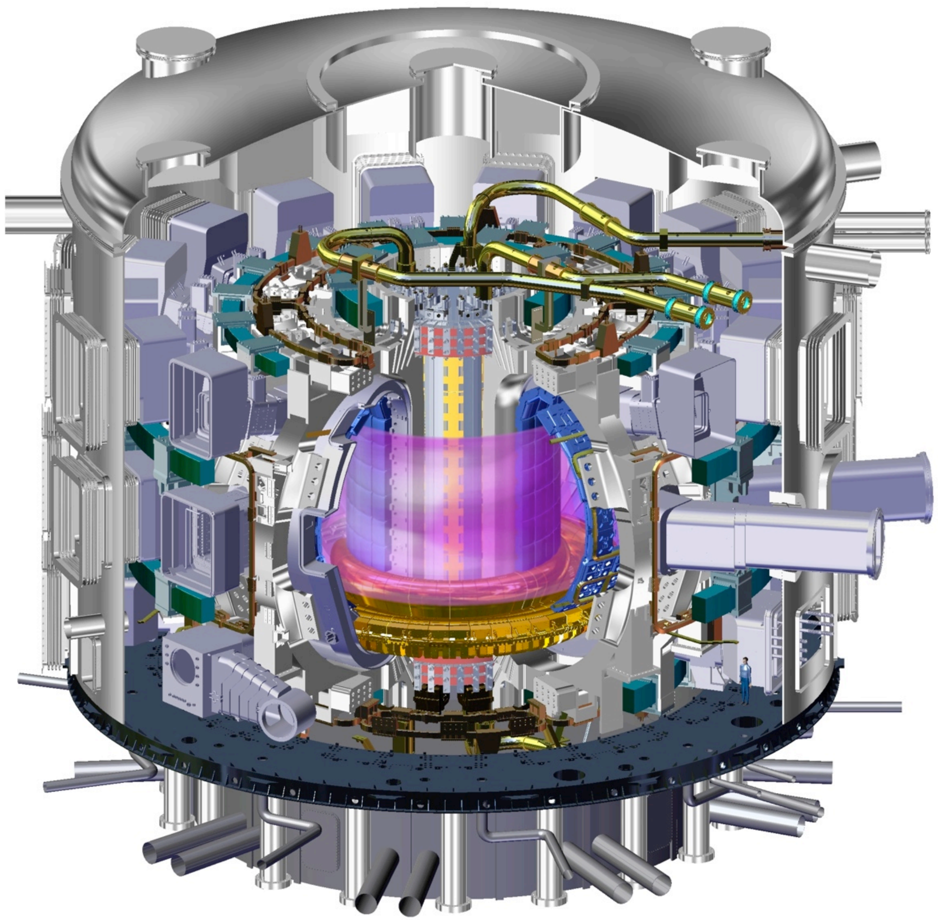
180 Hectares

10 Years of Construction

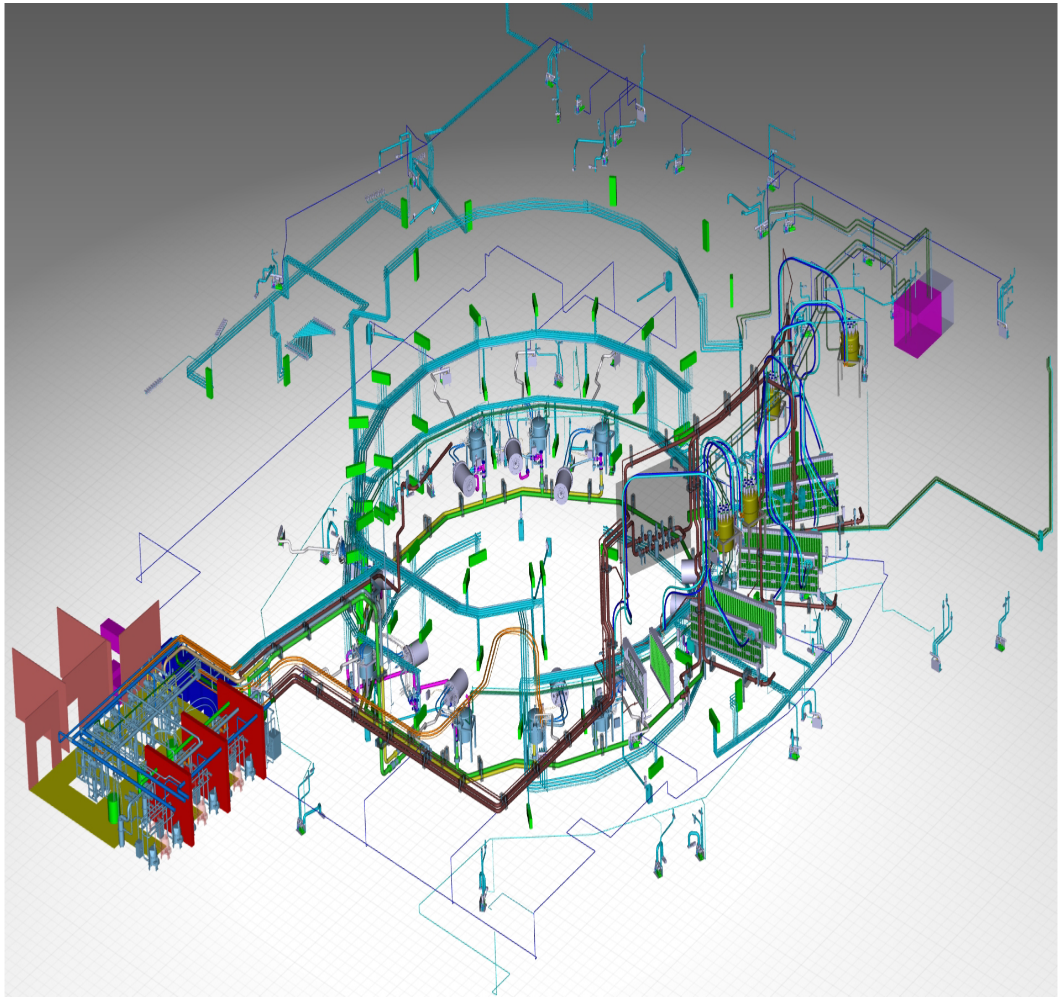
20 Years of Operation

ITER site construction is well underway

Nearly all Major Systems Require Vacuum

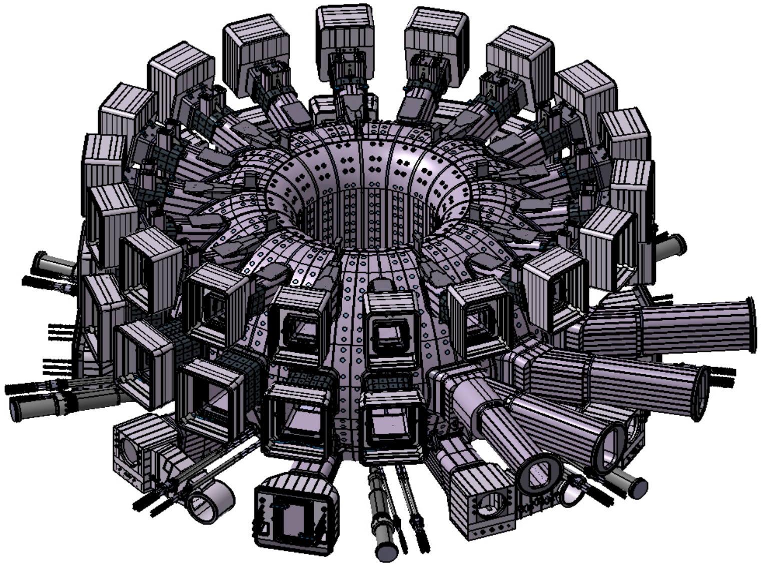


Cryostat vacuum(<10^{-4} Pa) 8500 m^3
Torus vacuum(~10^{-6} Pa) 1330 m^3
Neutral Beam vacuums(~10^{-7} Pa) 860 m^3
Cryogenic Guard Vacuum



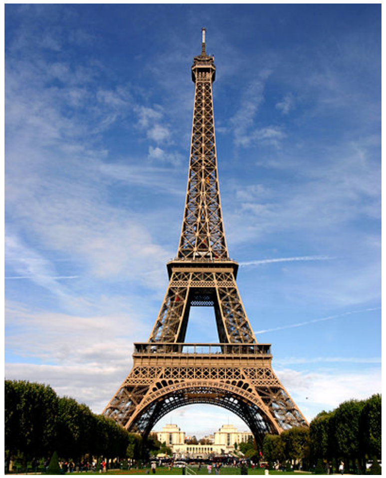
Service Vacuum System
Ion and Electron Cyclotron
Heating Systems Vacuums

Torus Vacuum Vessel Features



Vacuum vessel & In-vessel components: ~8000 t

Eiffel Tower ~7300 t



19.4 m diameter
11.3 m tall

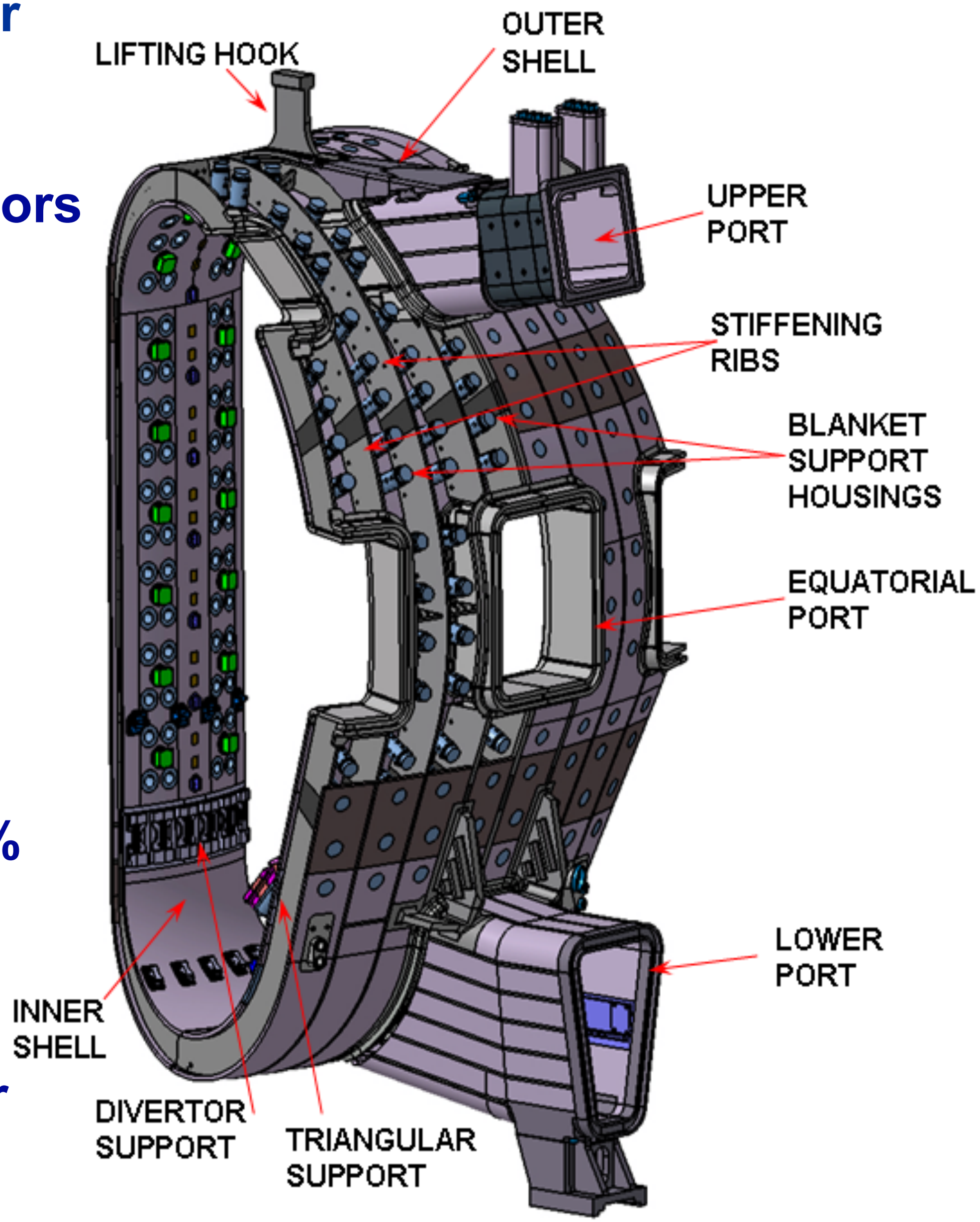
9 each 40° sectors (~600 t each)

Double-wall structure

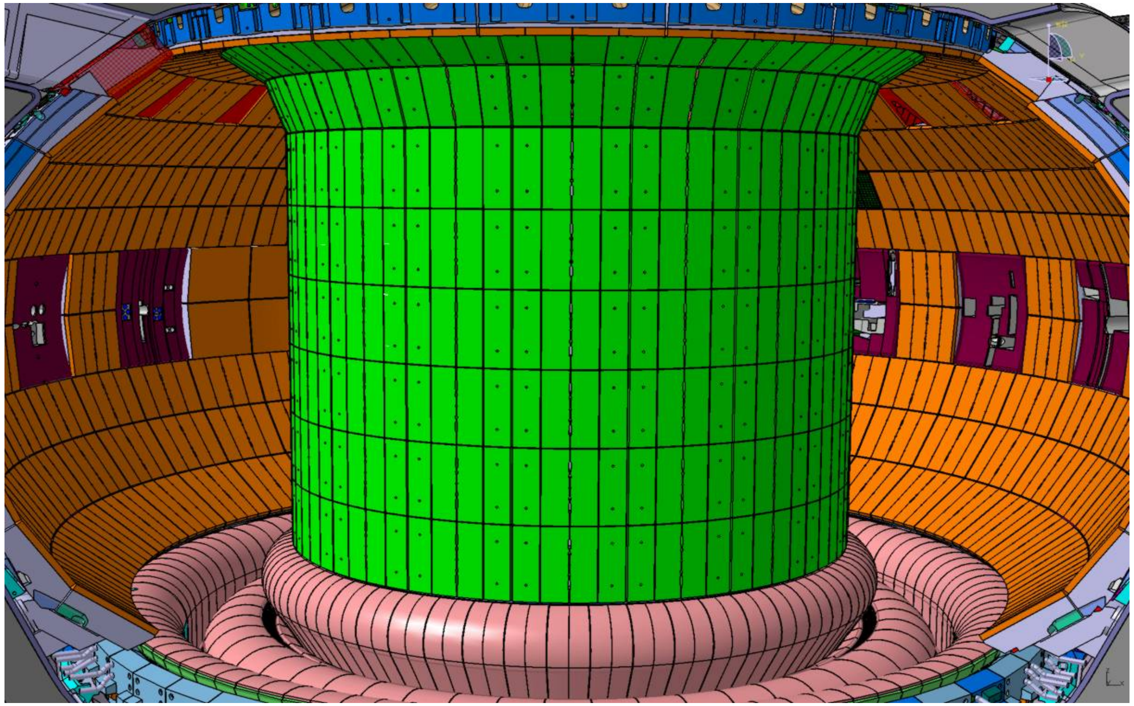
Shielding and cooling water between shells

304 SS + 1 - 2 % boron, SS 430 ferromagnetic

34 Ports (upper equatorial and divertor)



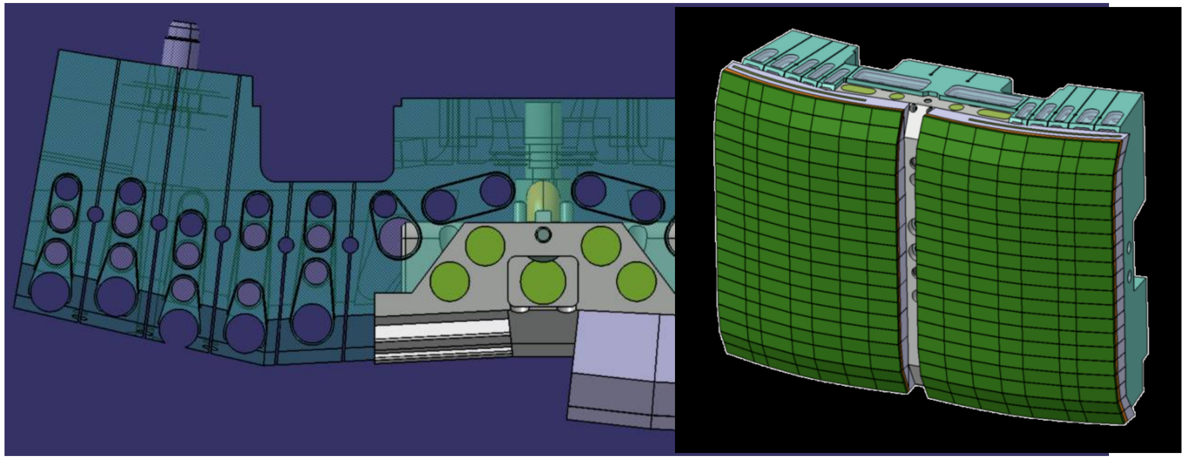
In-vessel Components (First Wall)

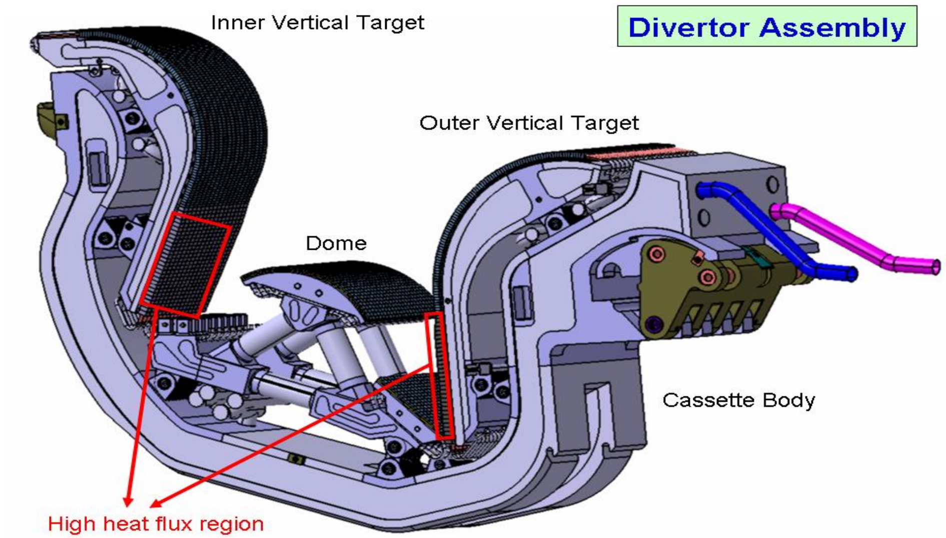


440 blanket modules (<5 MW/m^2) and 54 divertor cassettes (20 MW/m^2) providing:-

1) **High heat flux neutralizing surfaces.**
2) **Neutron shielding**
3) **Thermal shielding**
4) **Start up limiter**

	Shield	First Wall
Vacuum exposed area (m²)	2200	1760
Pressurized wetted area (m²)	2200	1380
Pressurized wetted weld length (m)	2200	274

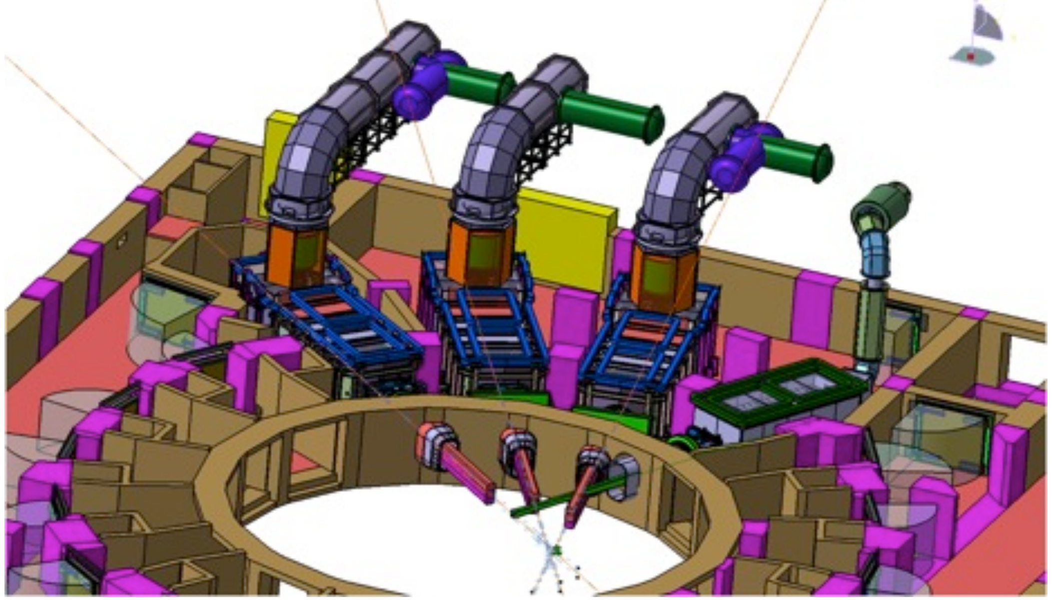


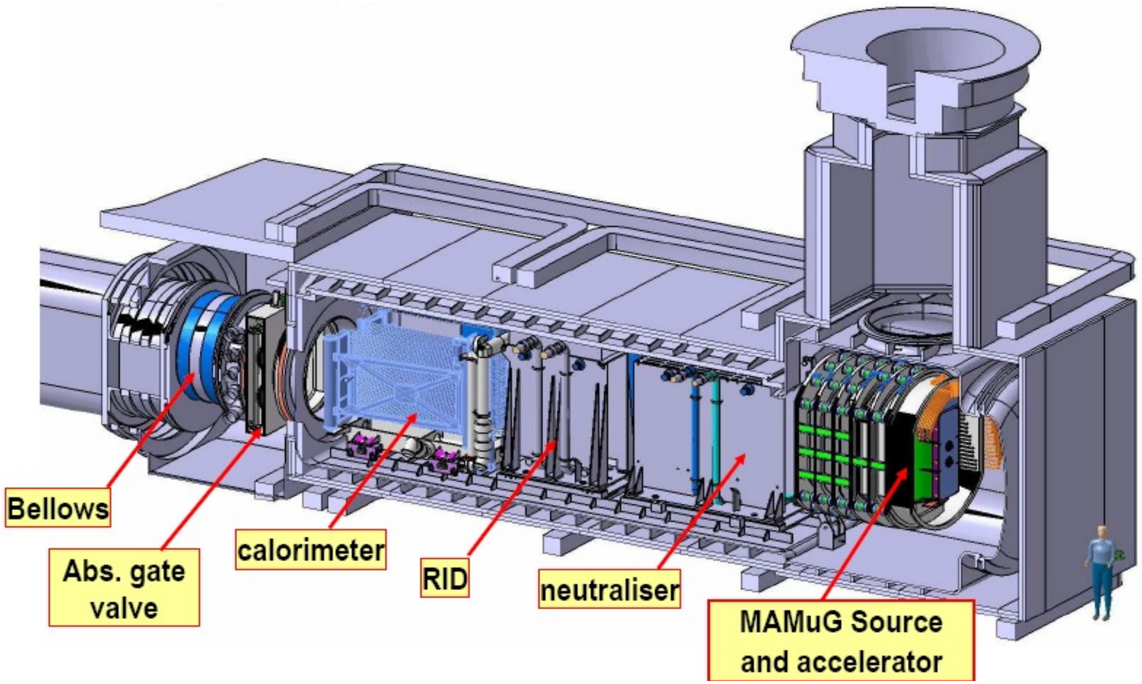


Plasma Heating Systems (Vessel Ports)

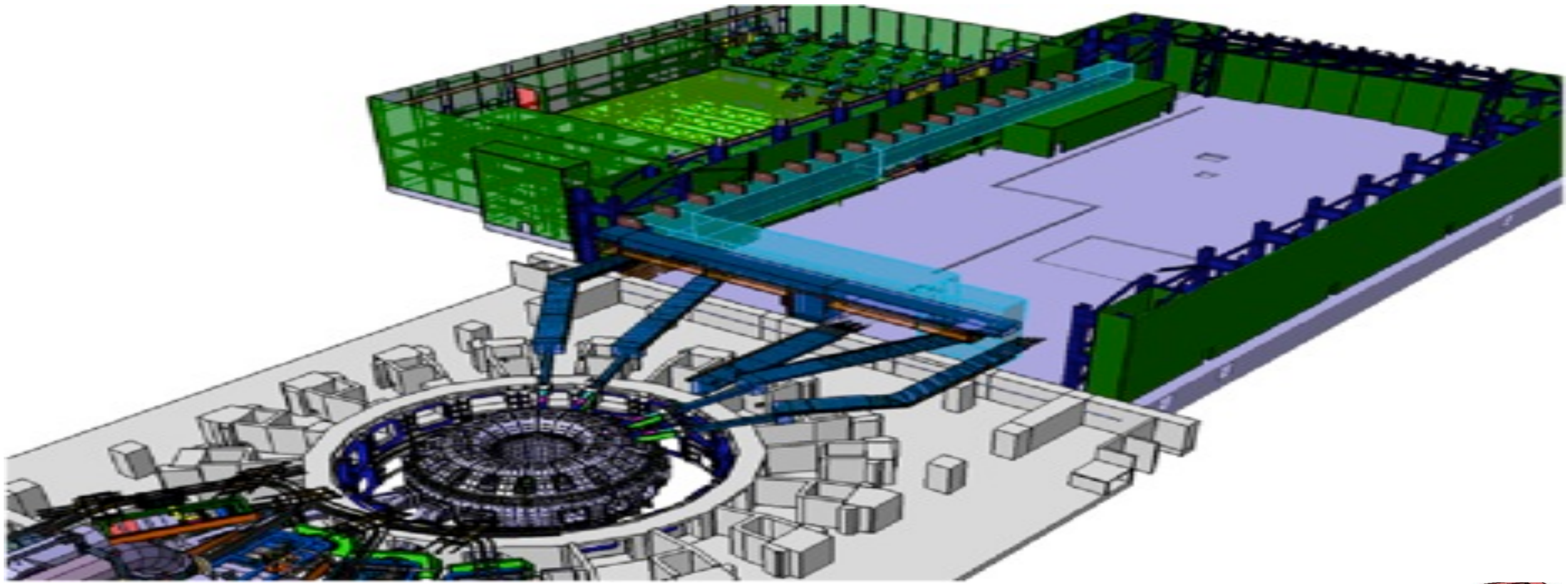
3 Neutral beams systems
1 MeV source
Up to 50MW

1 Diagnostic Neutral beams systems





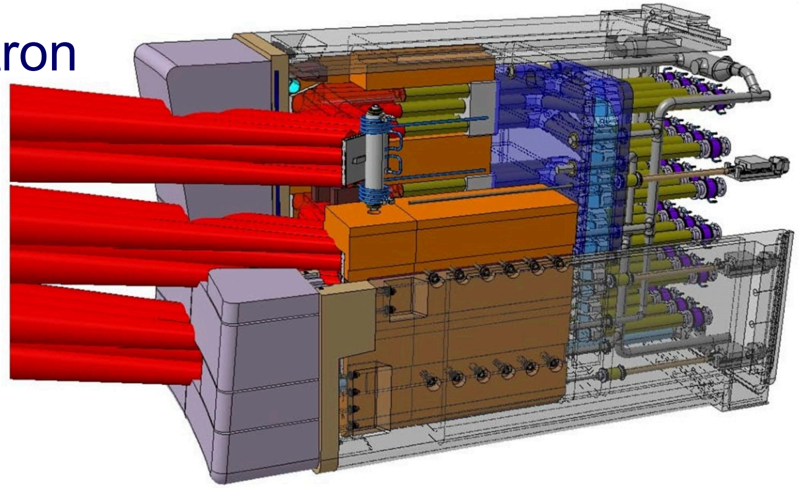
Plasma Heating Systems (Vessel Ports)



20MW Electron Cyclotron Heating

170GHz

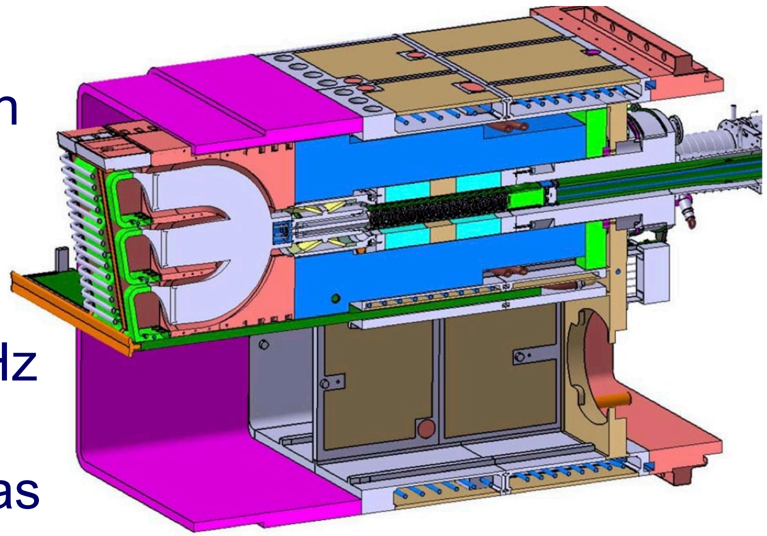
5 launchers



20MW Ion Cyclotron Heating

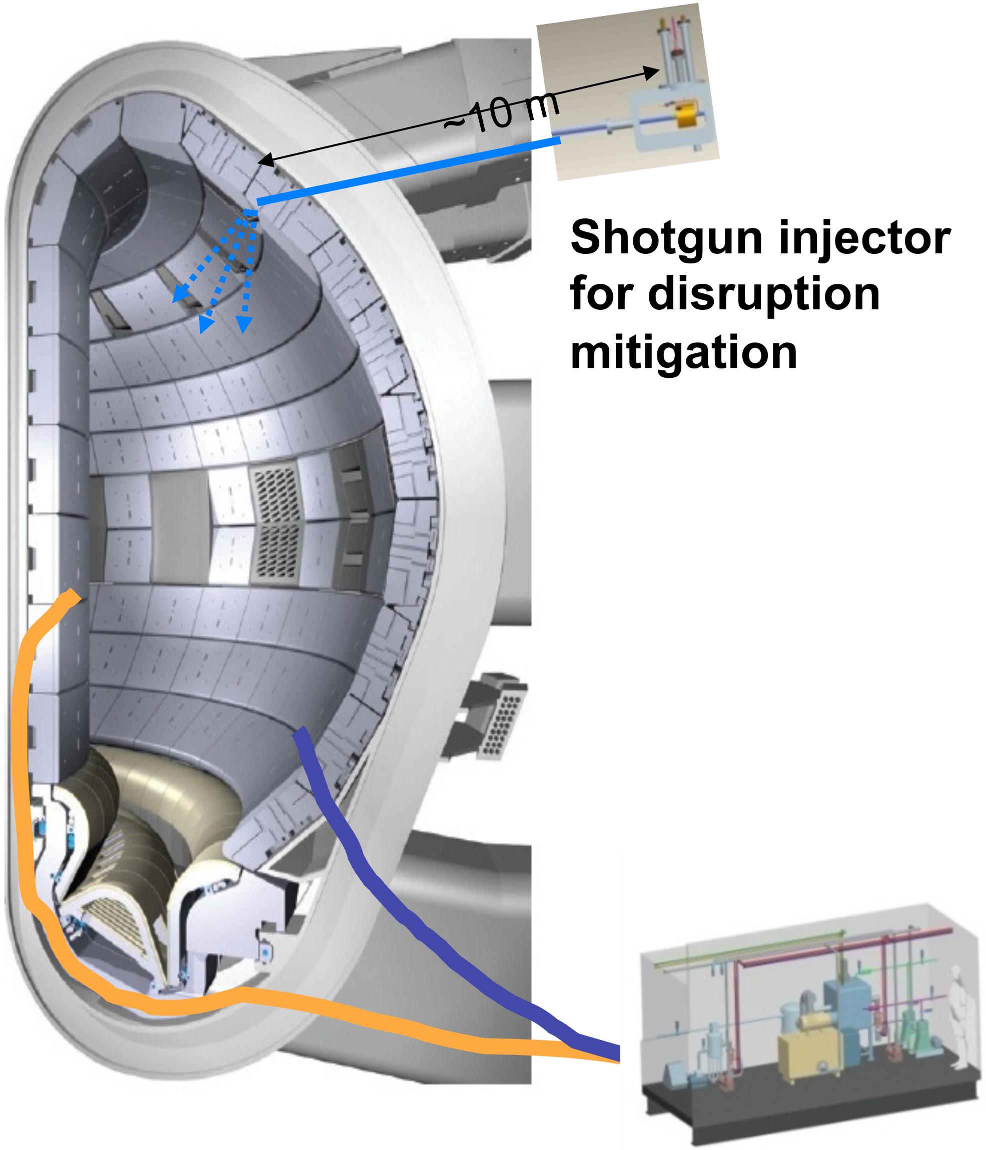
40-55 MHz

2 antennas

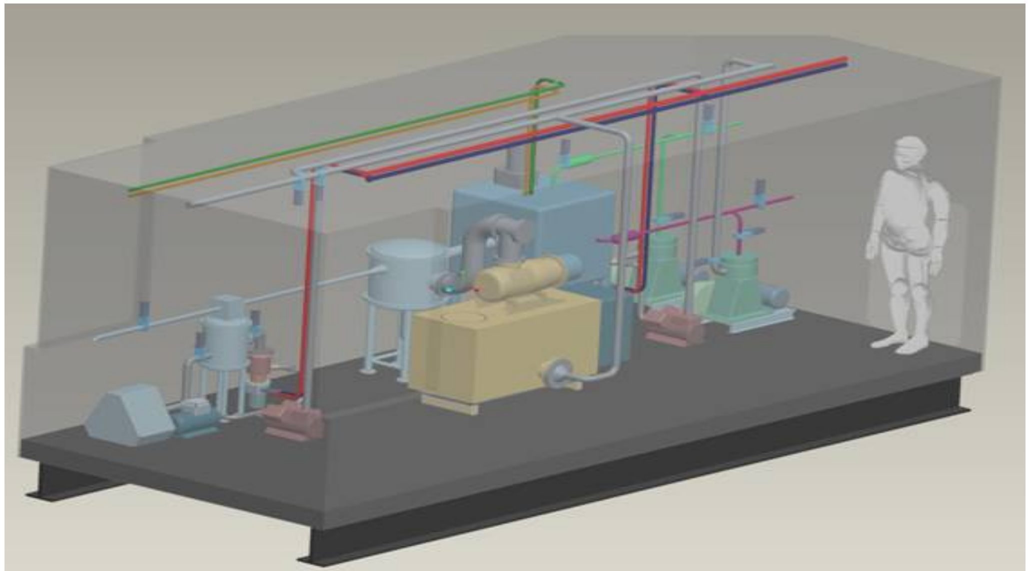


Pellet Injection Fueling System

- **Provide deuterium and tritium fuel to plasma core**
- **Mitigate impact of edge localized modes (ELMs)**
- **Mitigate disruptions with large “shotgun” pellets**



Shotgun injector for disruption mitigation



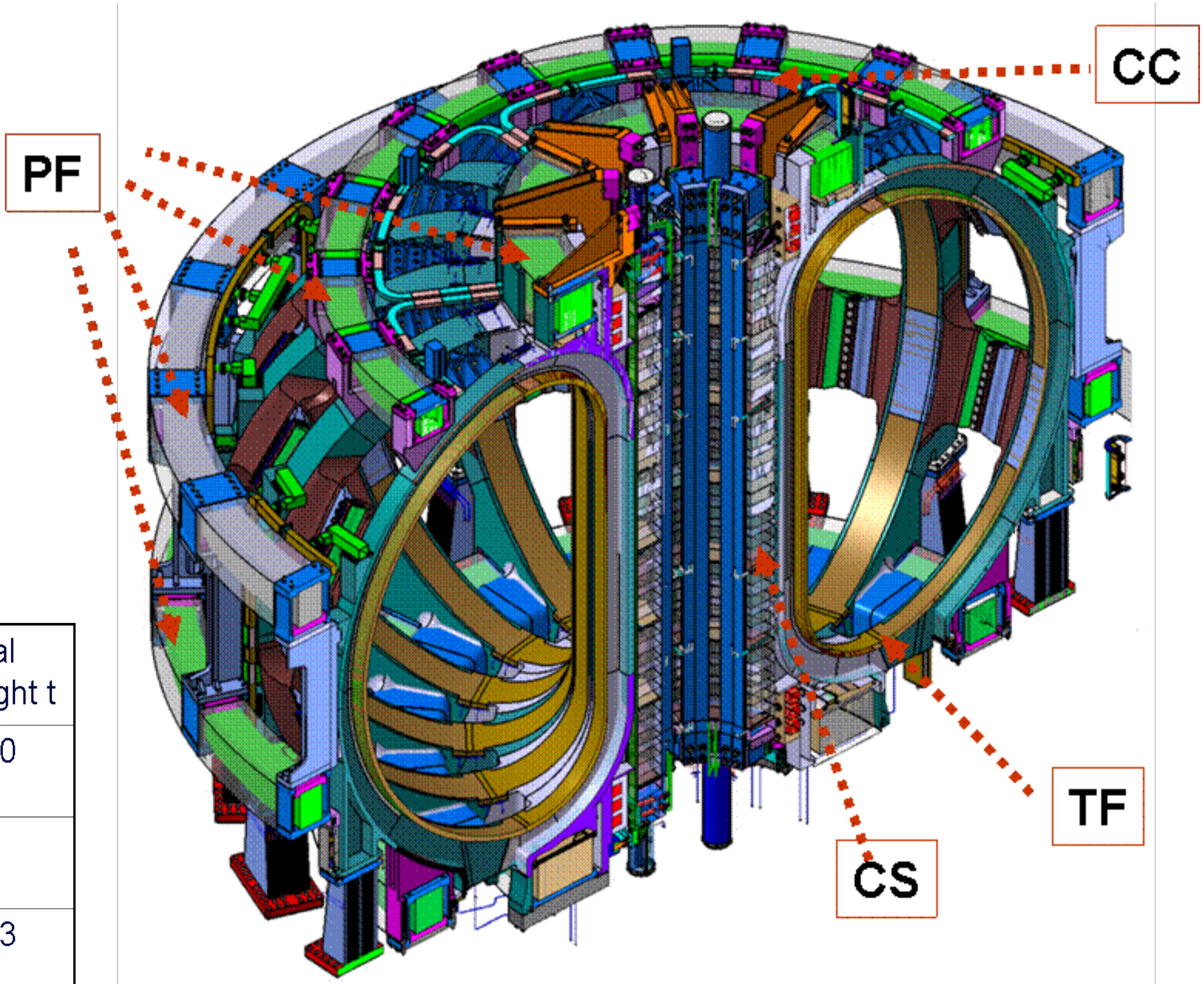
Pellet injectors for fueling and ELM pacing

Magnet Systems

48 superconducting coils:-
- 18 Toroidal Field coils
- 6 Central Solenoid coils
- 6 Poloidal Field coils
- 9 pairs of Correction Coils

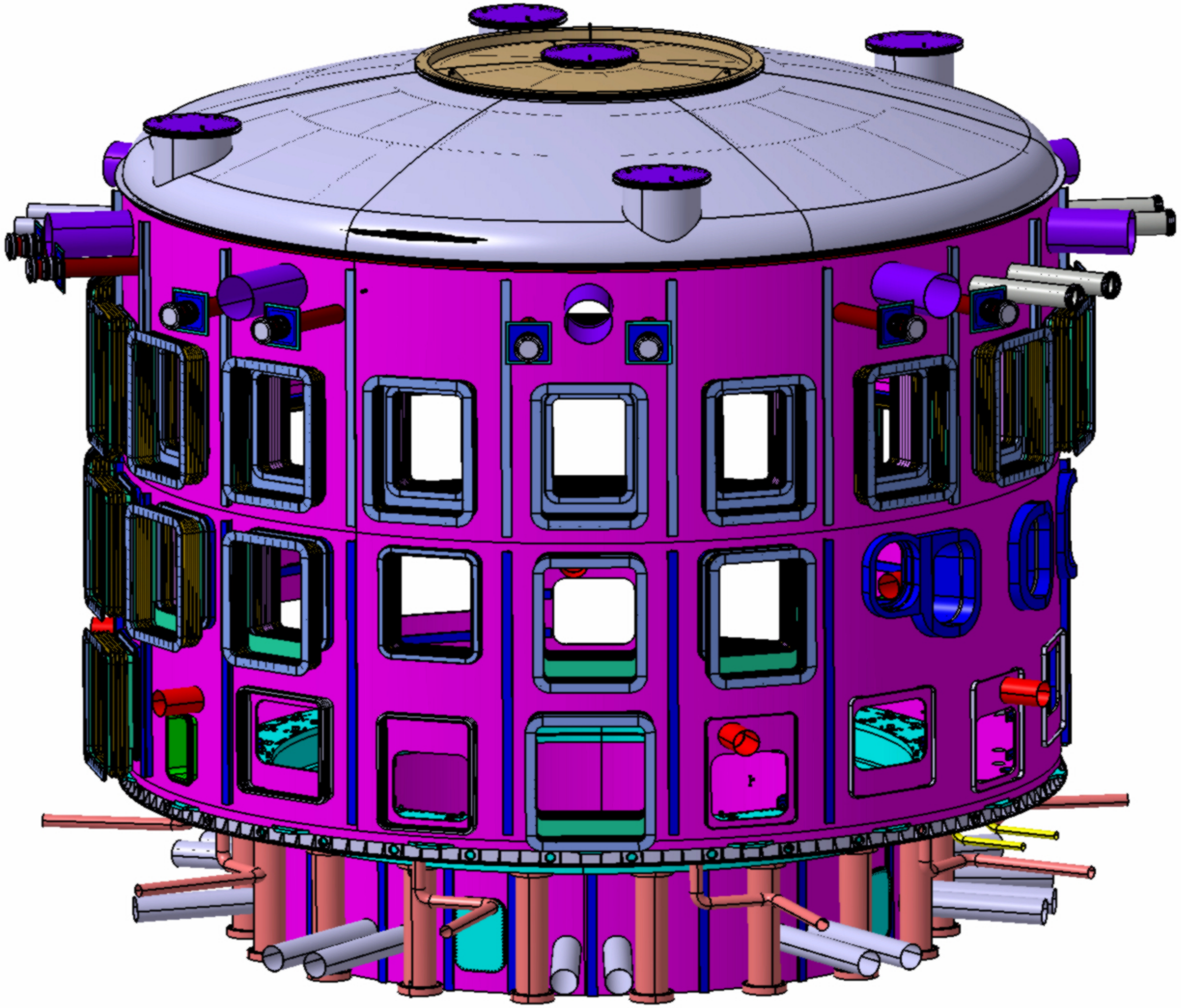
In-vessel ELM coils

System	Energy GJ	Peak Field	Total MAT	Cond length km	Total weight t
Toroidal Field TF	41	11.8	164	82.2	6540
Central Solenoid	6.4	13.0	147	35.6	974
Poloidal Field PF	4	6.0	58.2	61.4	2163
Correction Coils CC	-	4.2	3.6	8.2	85



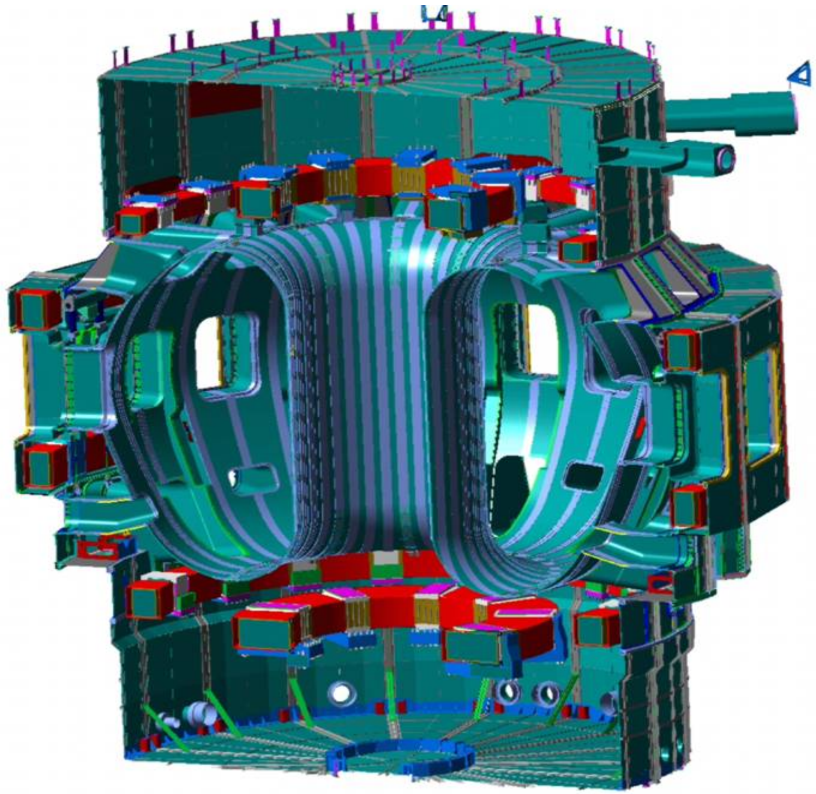
ITER Field ~10 Tesla

Cryostat



Diameter	29.2 meters
Height	~29 meters
Weight	~3300 tons
Operation Pressure	$< 10^{-4}$ Pa
Structure Material	Type 304 & 304L

Thermal Shield



- Provides the barrier for thermal loads from warm components (up to 350 C) to the superconducting coils and structures that operate at 4.5K.

- Operates at 80 K – maintained by gaseous He in the cooling pipes ~32 km - OD13.5mm - 304L - 2mm thick.

- Stainless steel panels are silver coated for low emissivity (0.05)

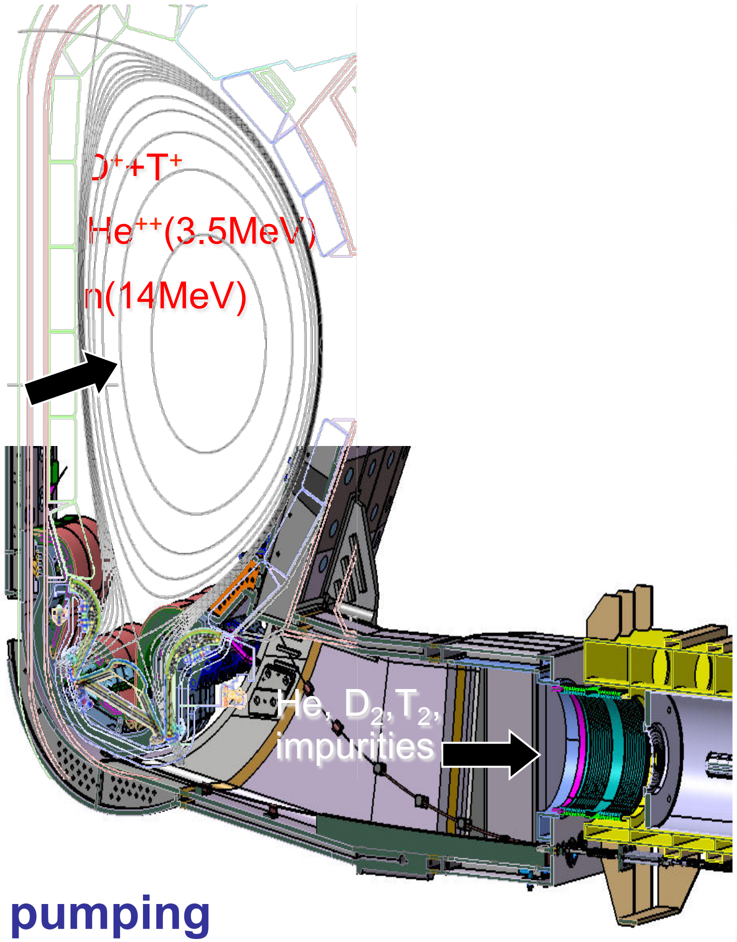
- Total mass nearly 1000T

Role of Fueling and Pumping in Tritium Cycle

Closed loop tritium fuel cycle

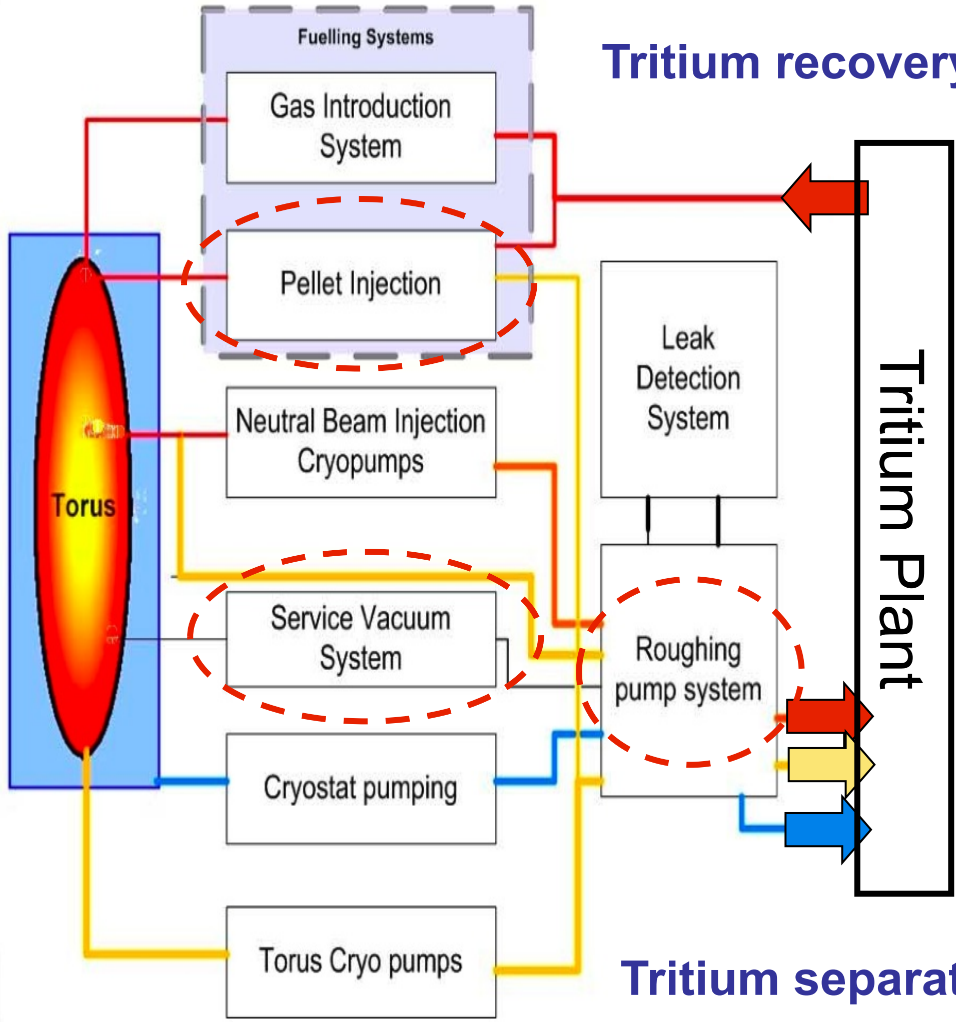
Continuous D/T fuelling by pellet injection

D_2,T_2 Fuel



Continuous pumping of H, D, T and He gases through cryogenic pumps, vacuum lines and roughing pumps

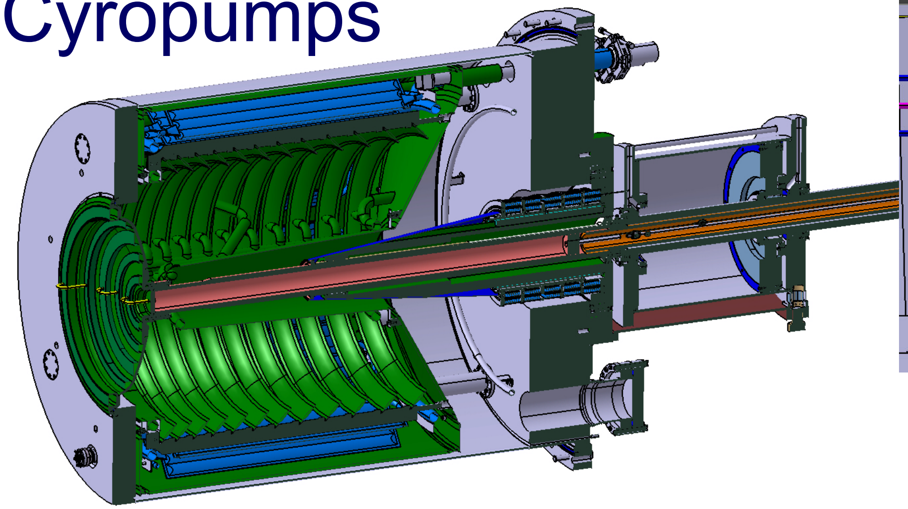
Tritium recovery

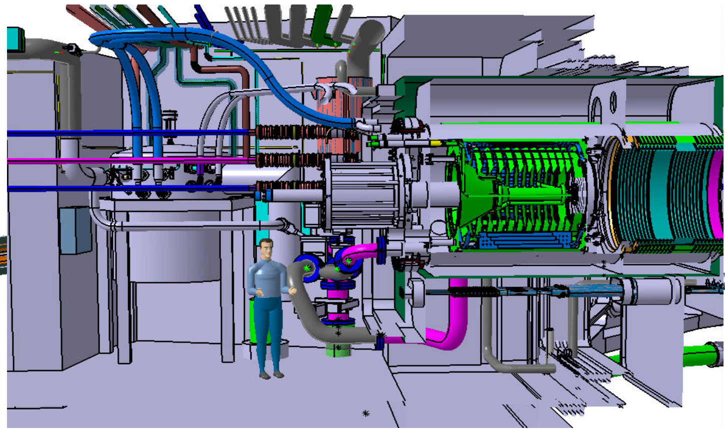


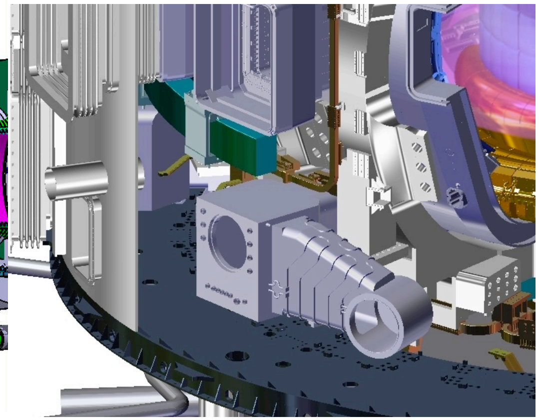
Tritium separation

3 Different Custom Cryogenic Pumping Systems

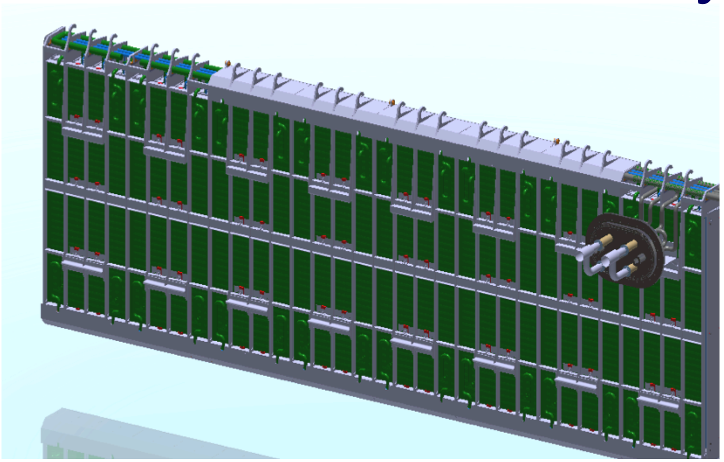
Torus and Cryostat Cyropumps

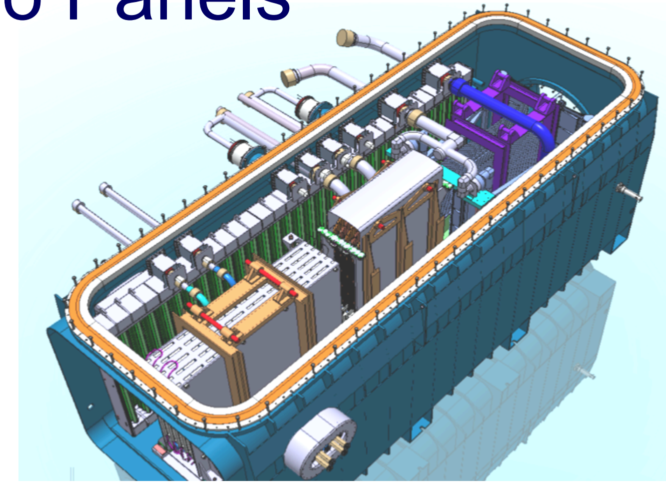




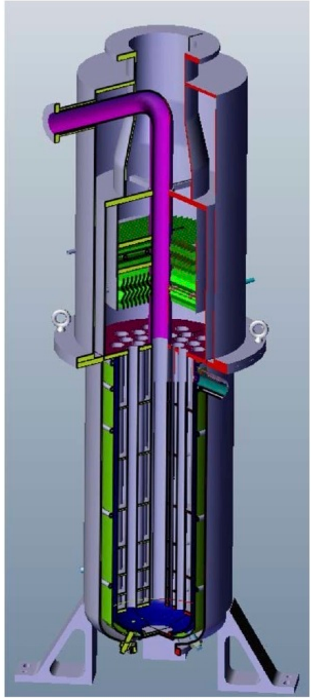


Neutral Beam Cryo Panels





Roughing Cryogenic Viscous Compressor



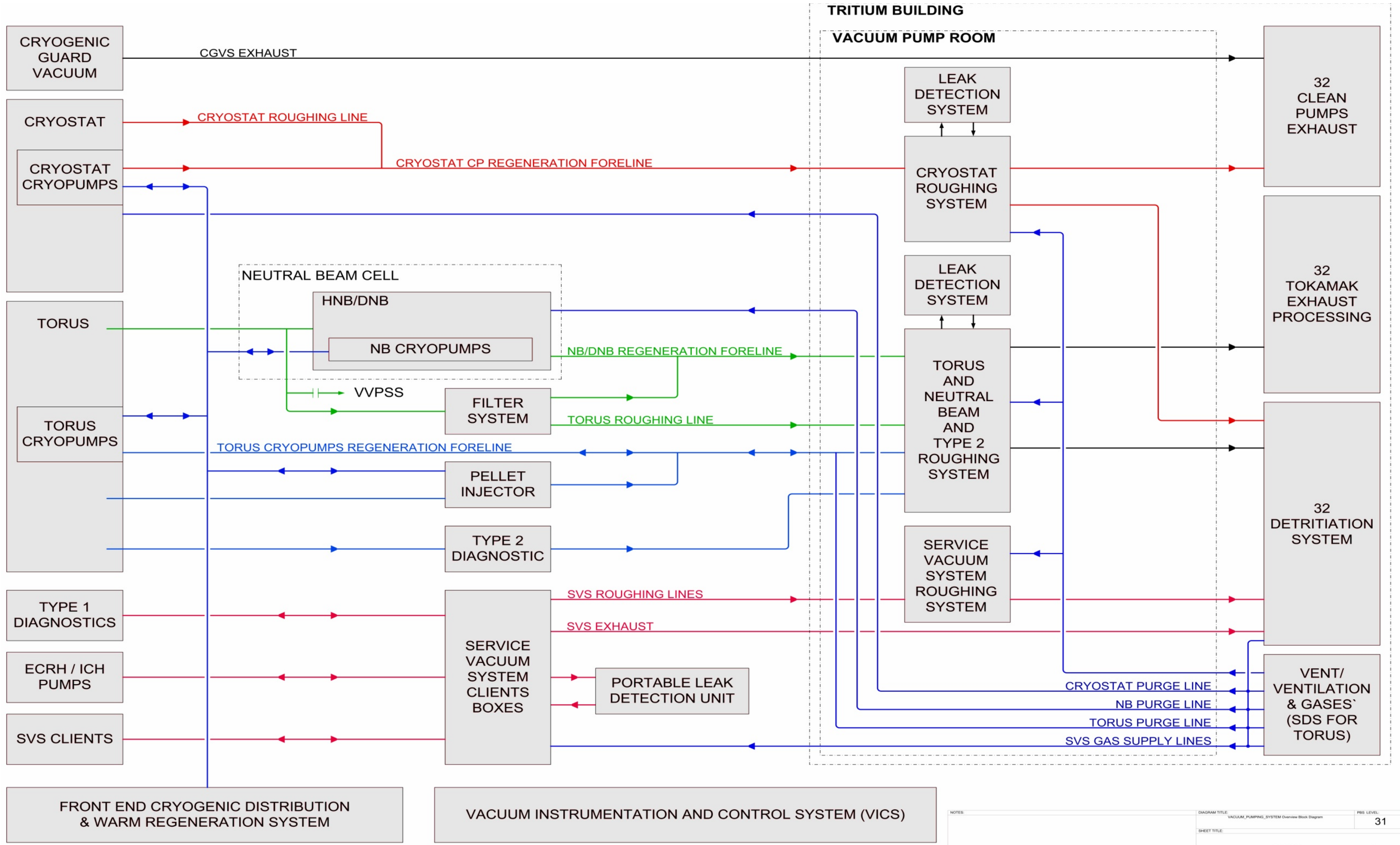
Roughing System Performance

- Torus ~1400m ^{3} , 10^5Pa to 10Pa in 24 Hours
- 1 torus cryopump, ~18m ^{3}, max 40KPam^3 (Hydrogen isotopes) , to 10 Pa in 150 sec.
- Primary seals – metal
- Secondary seals (Service Vacuum) - EPDM

- Cryostat ~8500m ^{3} , 10^5Pa to 10Pa in 24 Hours
- 1 cryostat, ~18m ^{3}, max 30KPam^3 (Helium + Hydrogen) , to 10 Pa in 600 sec.

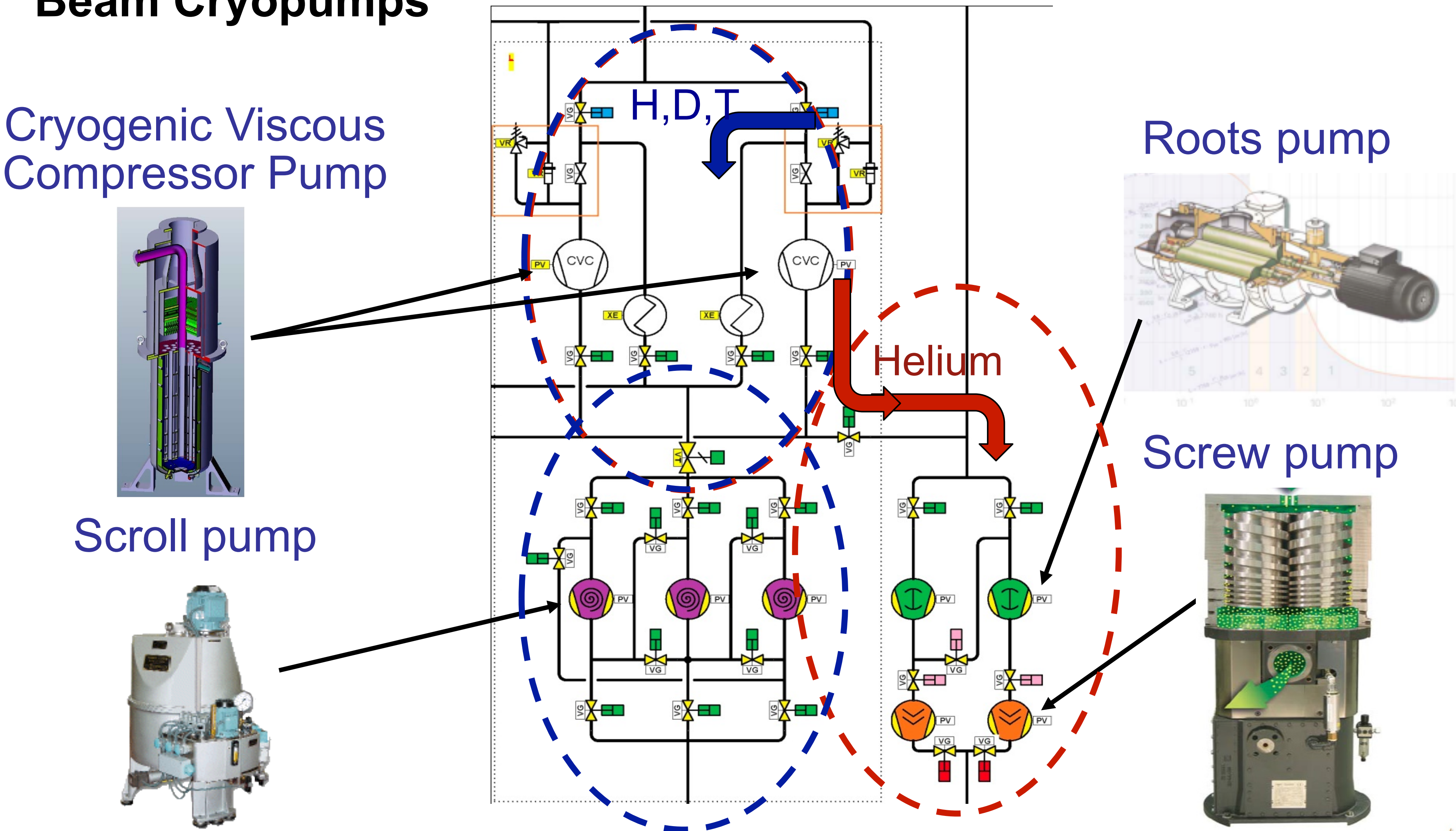
- NBIs ~ 170m ^{3} + 170m^3 + 170m^3 +120m^3 ,10^5Pa to 10Pa in 24 Hours.
- 4 NBI cryo pump ~170m ^{3}, max 300KPam^3 (Hydrogen isotopes) , to 10 Pa in 1.5 secs.

Full Vacuum System – Block Diagram

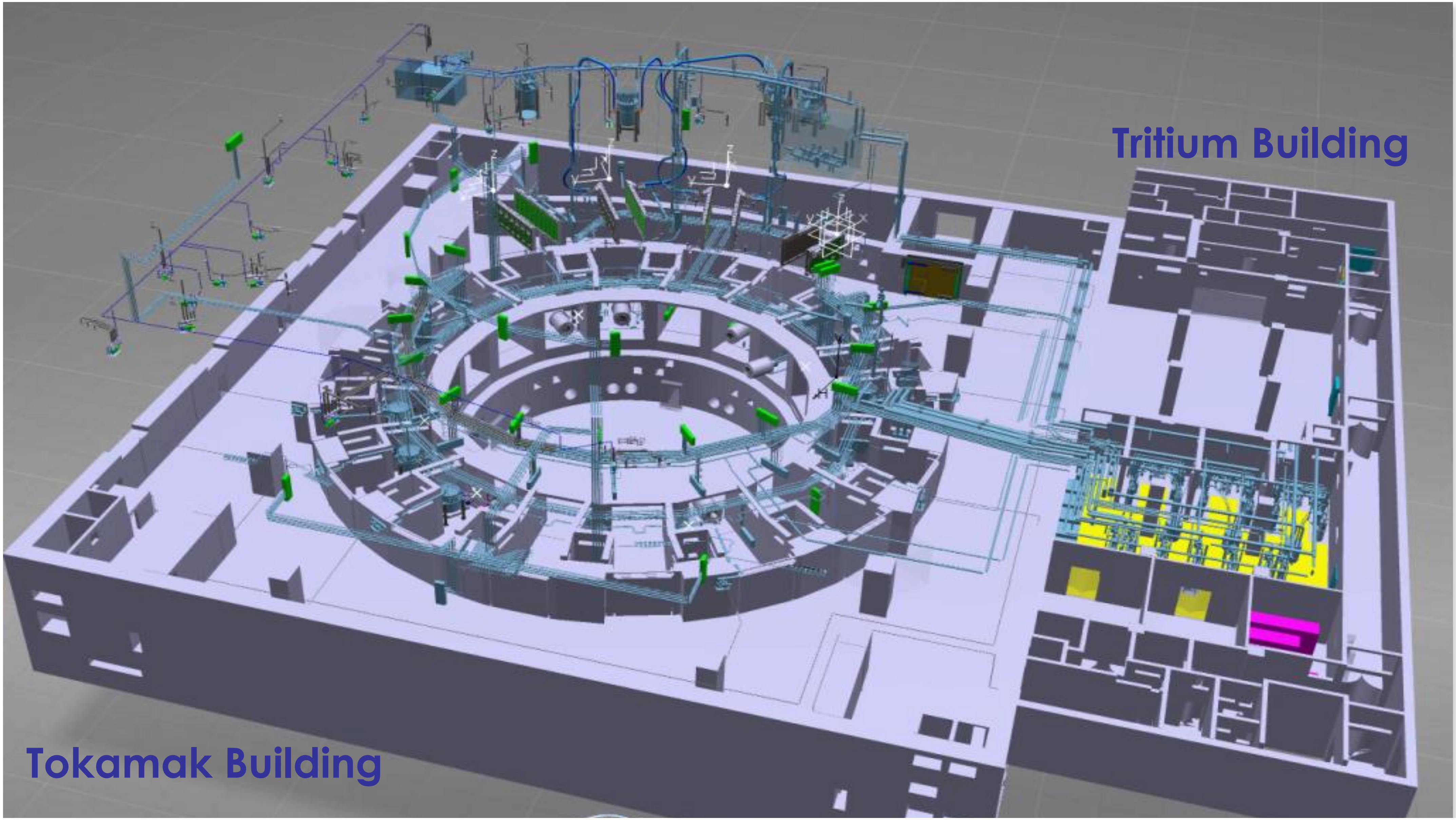


Roughing Pump Set can be Configured for Various Gas Flows

Tritium compatible backing pump trains for Torus and Neutral Beam Cryopumps

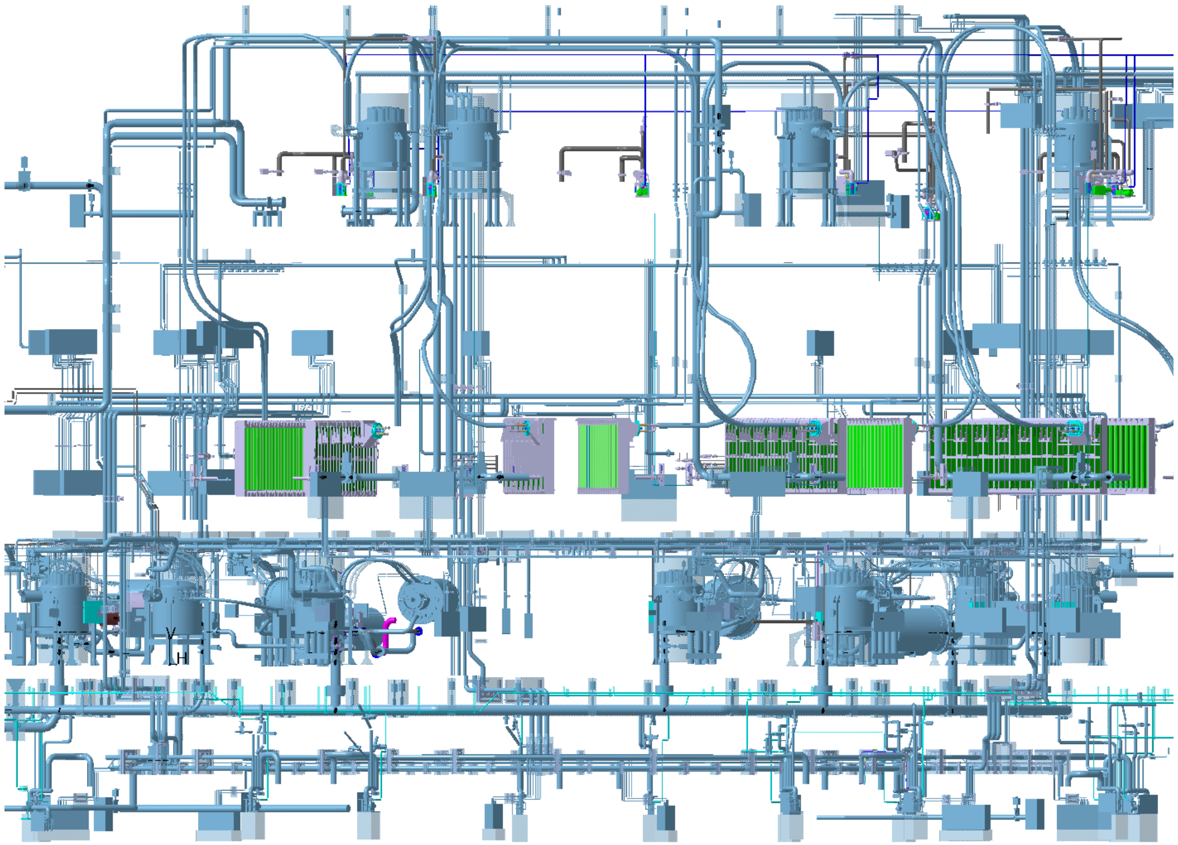


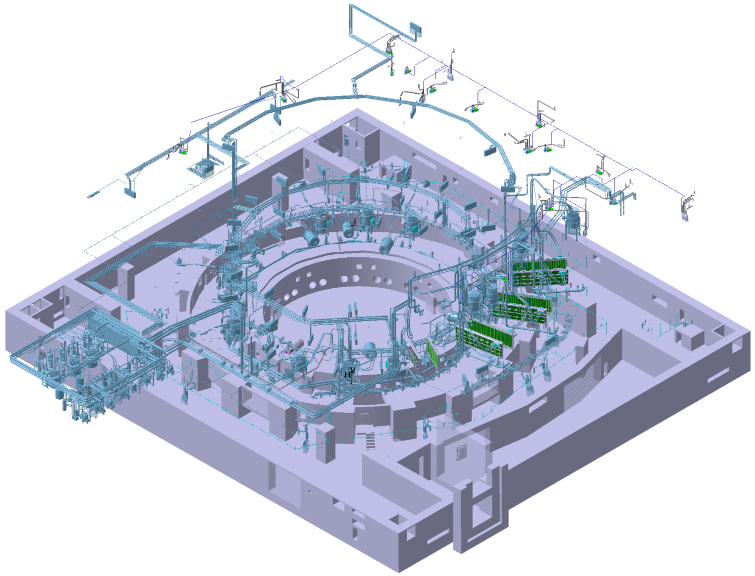
Vacuum Systems and Roughing Pump room

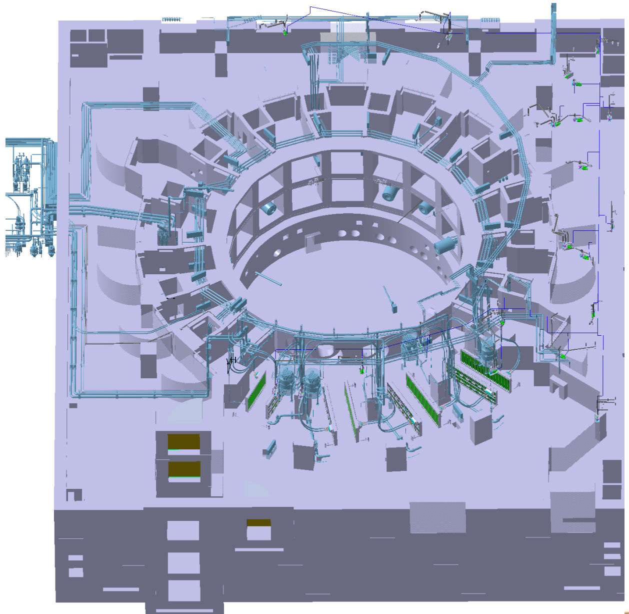


Containing ~ 400 vacuum pumps of ~10 different technologies

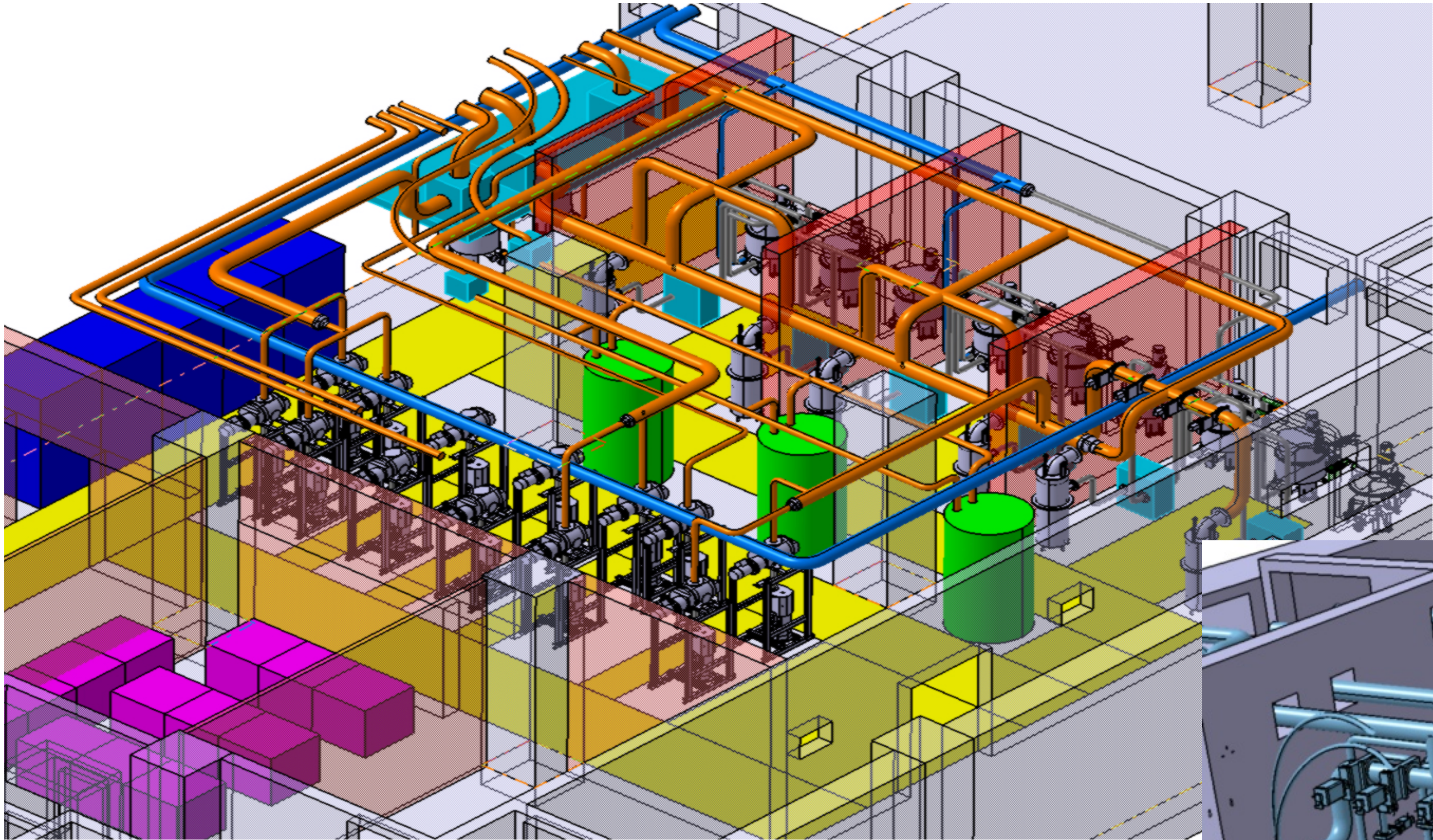
Vacuum Systems Extend to and Through all Floor Levels

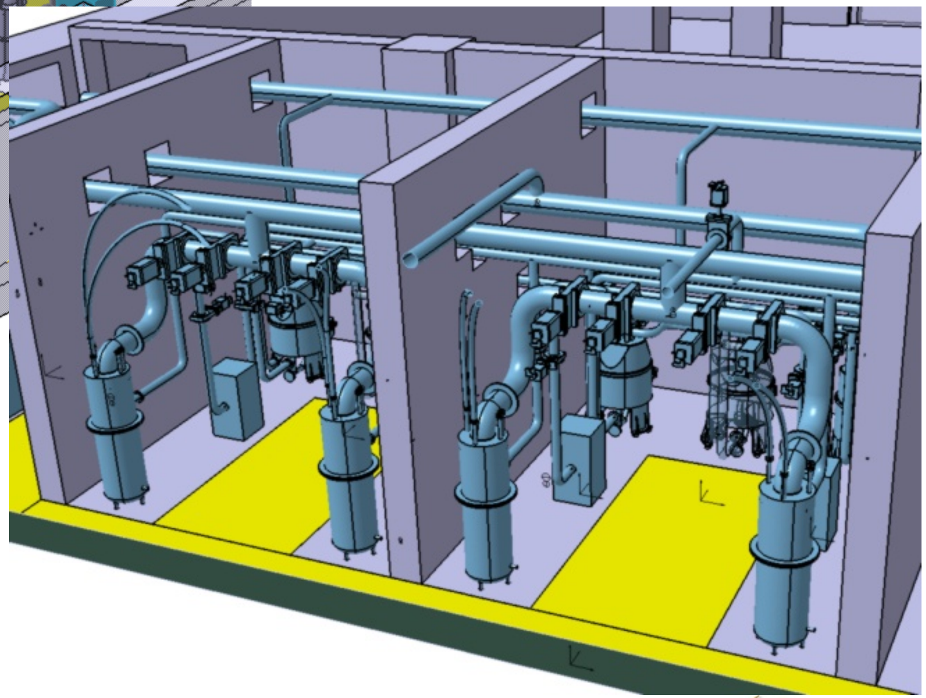




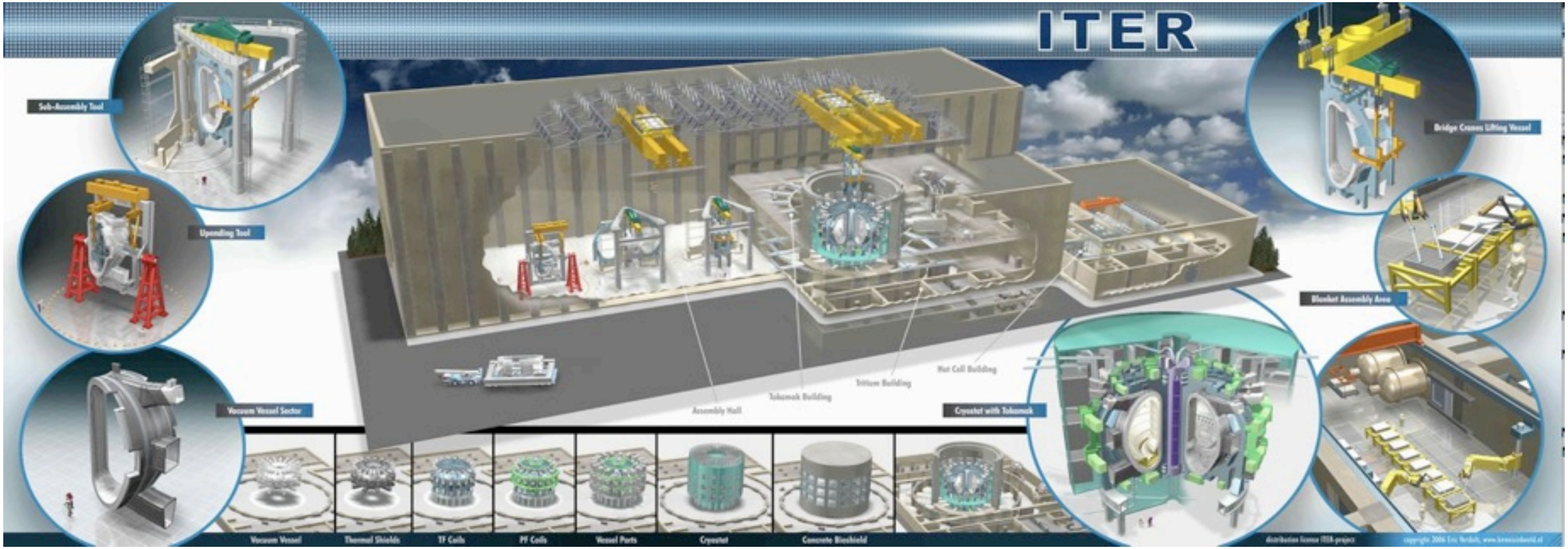


Proposed Roughing Pump room layout.





Some Assembly Required



Leak Checking Opportunity!

Backup Slides

The Potential of Deuterium -Tritium Fusion (with n -> Li breeding of T)

+

= 200,000 KWh

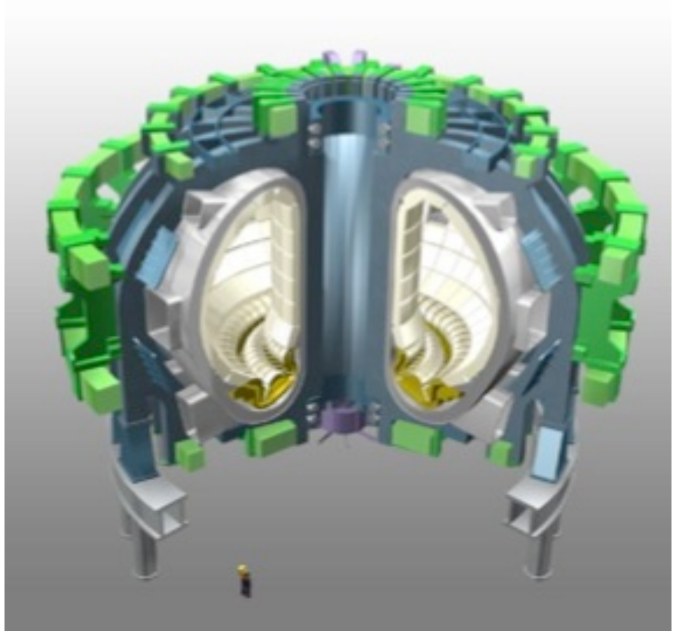
- Lithium from single laptop battery and deuterium from half a bathtub of water = fuel for 200,000 kilowatt hours of electricity
- 40 tonnes of coal equivalent
- Energy needs of one person for ~ 15-30 years

ITER is a very special partnership to address a global challenge and opportunity

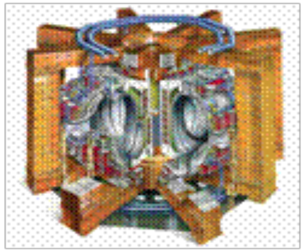
- A unique facility and program for the study of the science and technology of self-heated “burning” plasmas

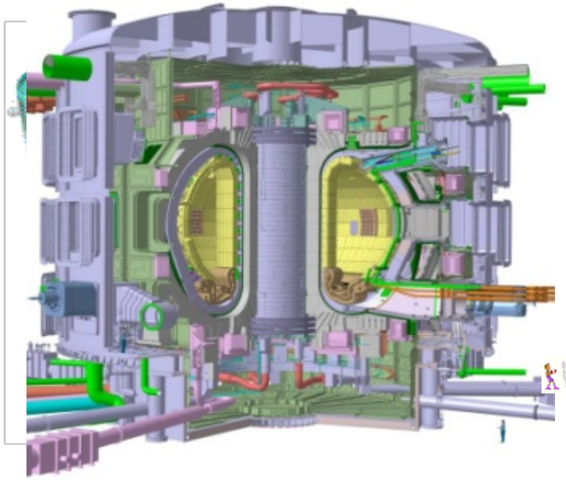
- An experiment in international collaboration on large science programs

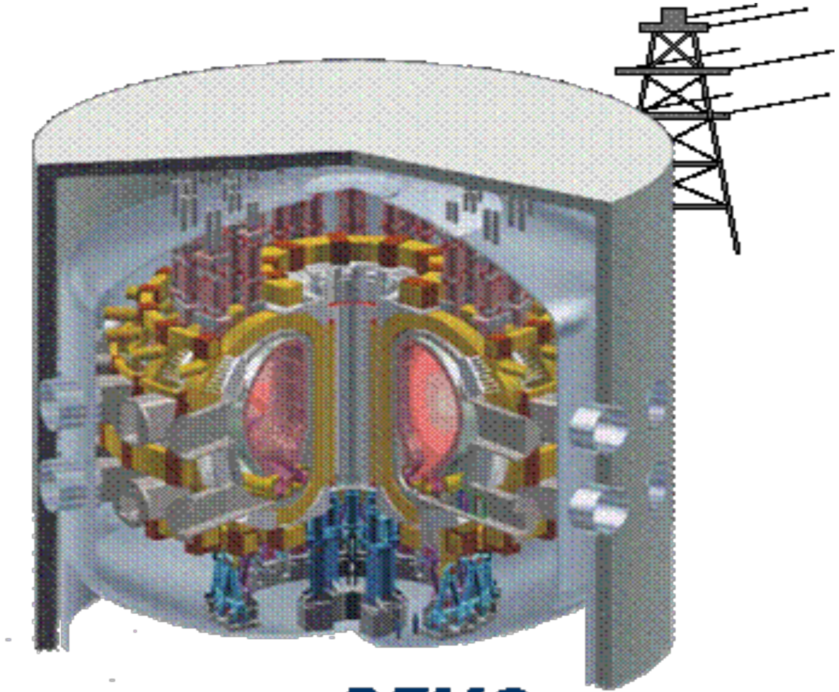
- Participants represents more than 1/2 the worlds population



ITER is the next significant step Toward a Power Producing Fusion Reactor



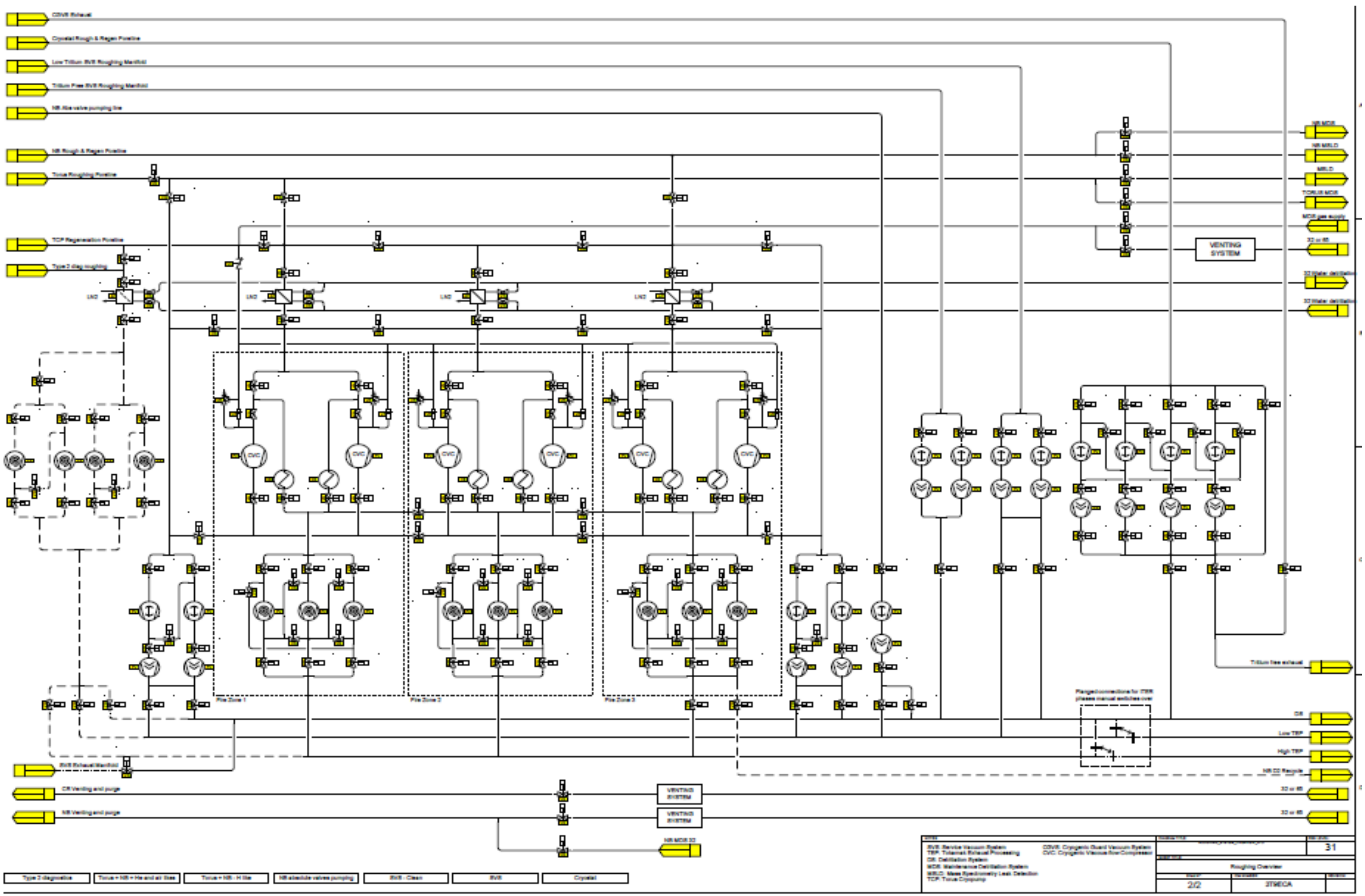




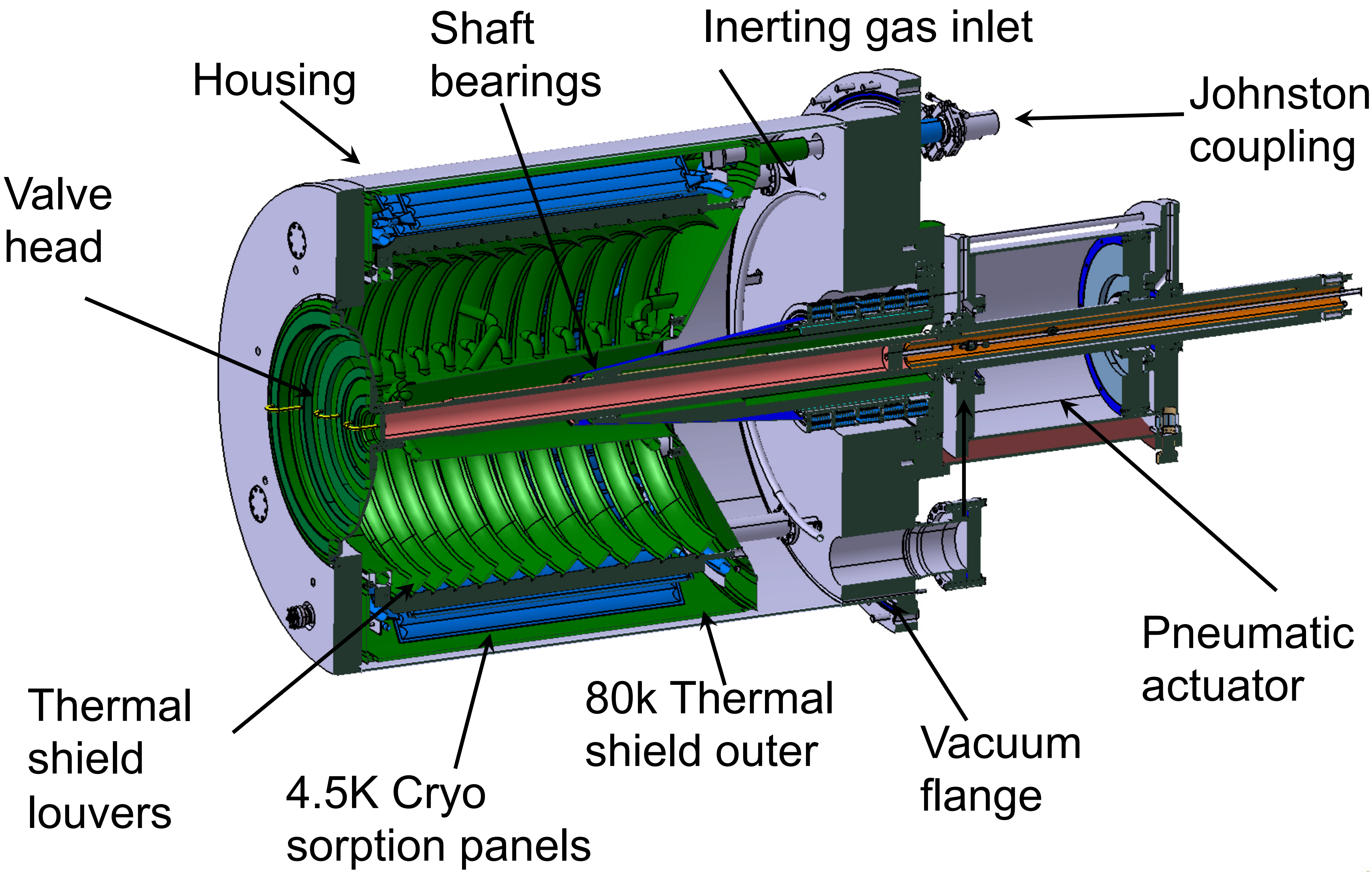
JET	ITER	DEMO
80 m^3	800 m^3	~ 1000 - 3500 m^3
~16 MW_{th}	~ 500 MW_{th}	~ 2000 - 4000 MW_{th}

- Dominant self heating ---------------->

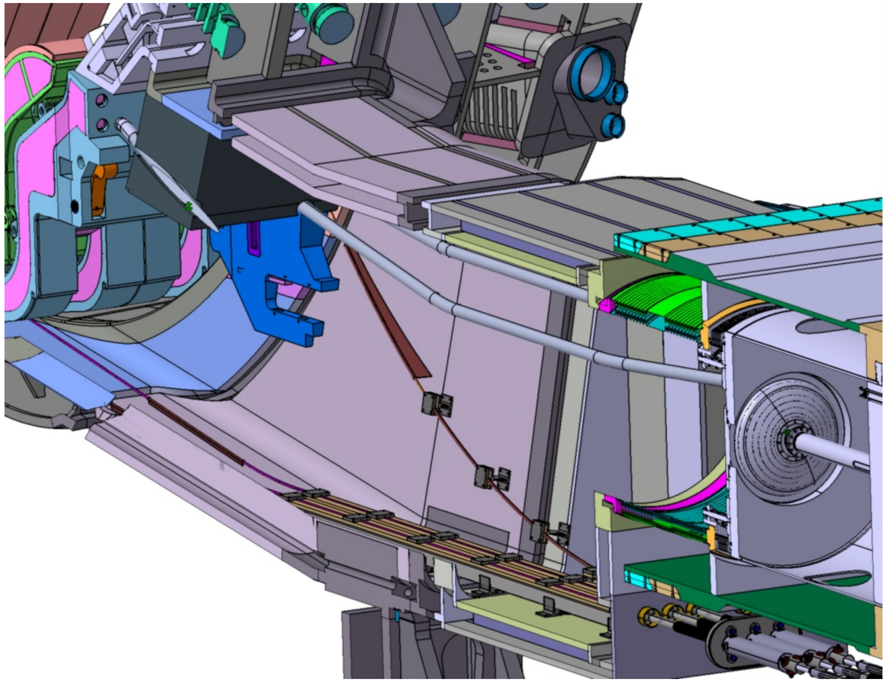
Proposed full Roughing System

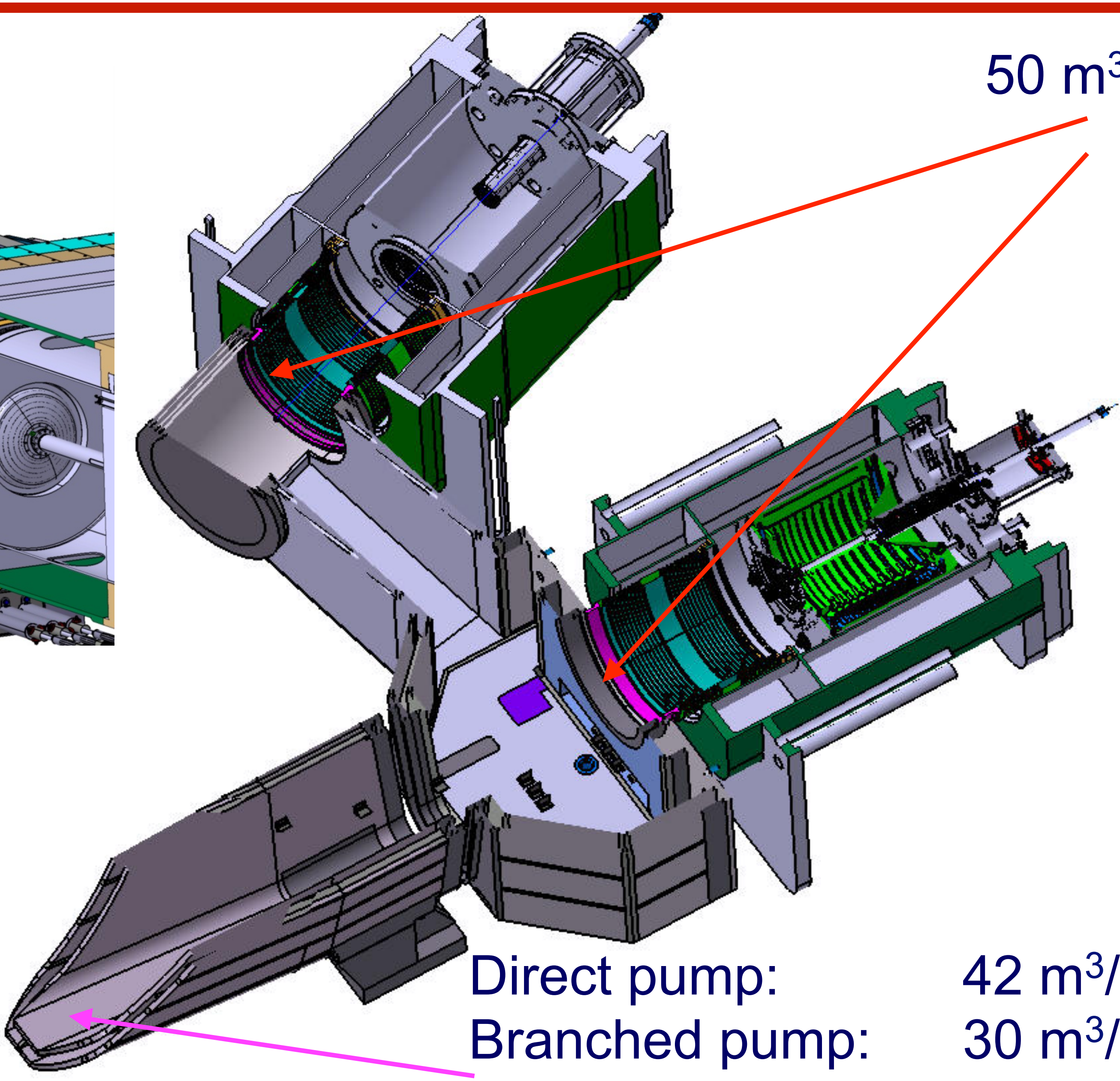


Torus and Cryostat Cryopumps design



DT Molecular Flow Pumping Speeds





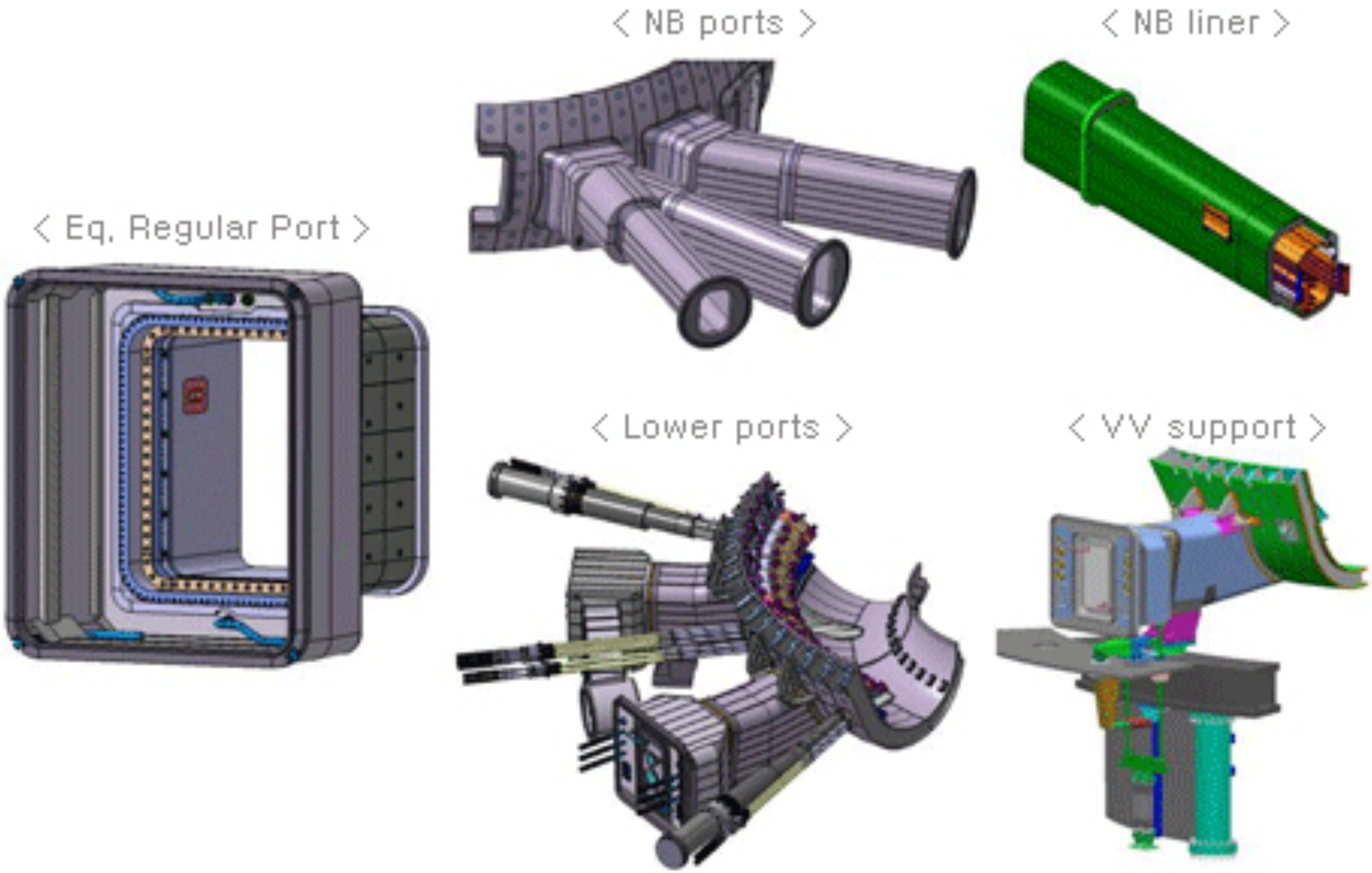
50 m^3/s

Main Chamber

8 pumps ~140m^3/s
4 pumps ~110m^3/s
(different ports)

Direct pump:	42 m^3/s
Branched pump:	30 m^3/s
Both pumps:	65 m^3/s

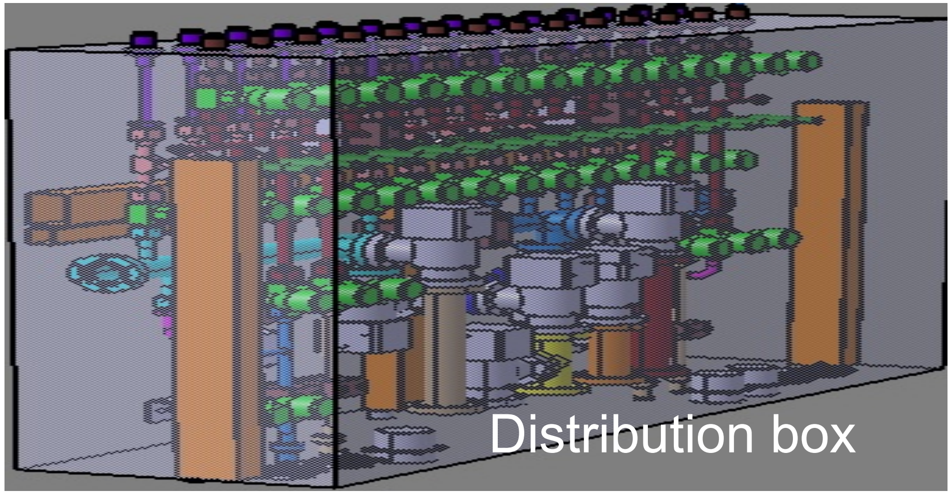
Torus Vacuum Vessel Subcomponents

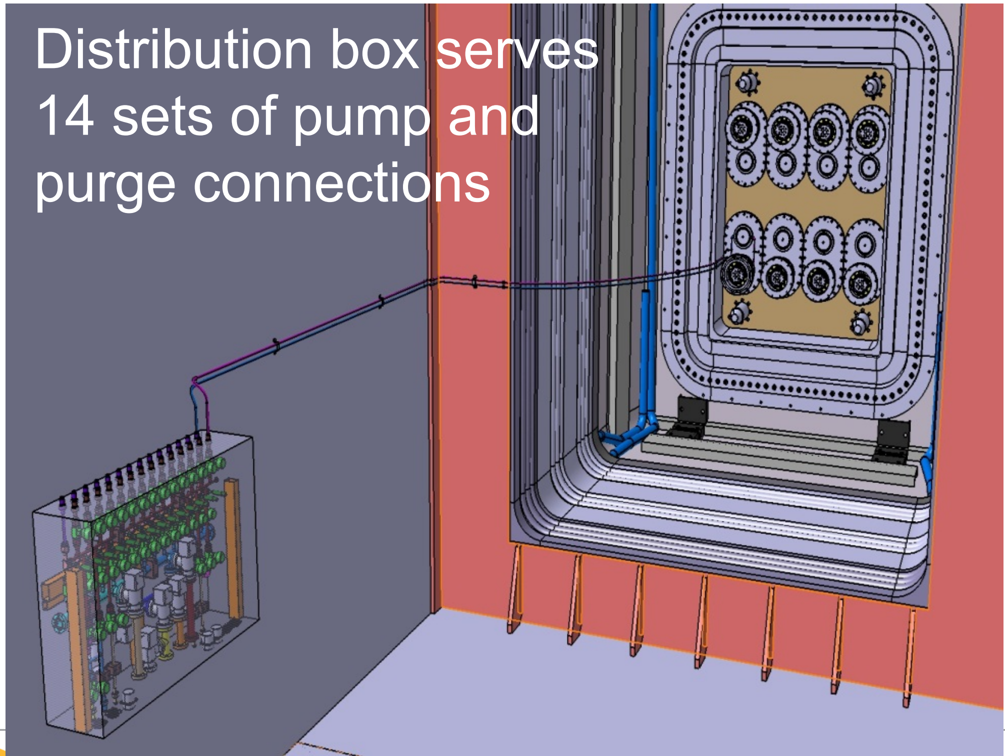


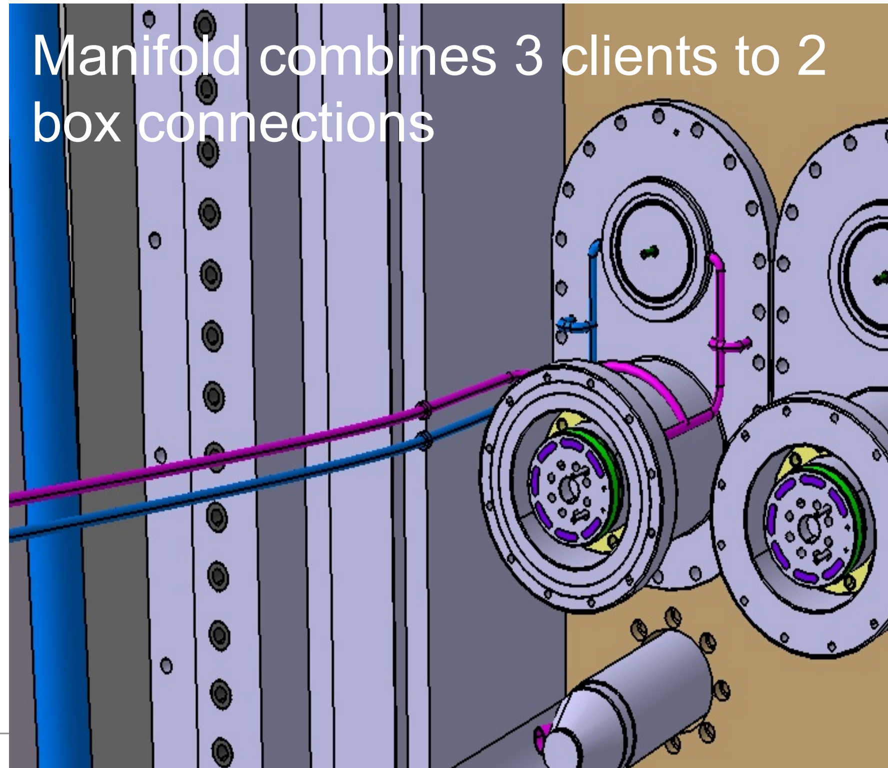
< Korea's Procurement Items for Port Structures >

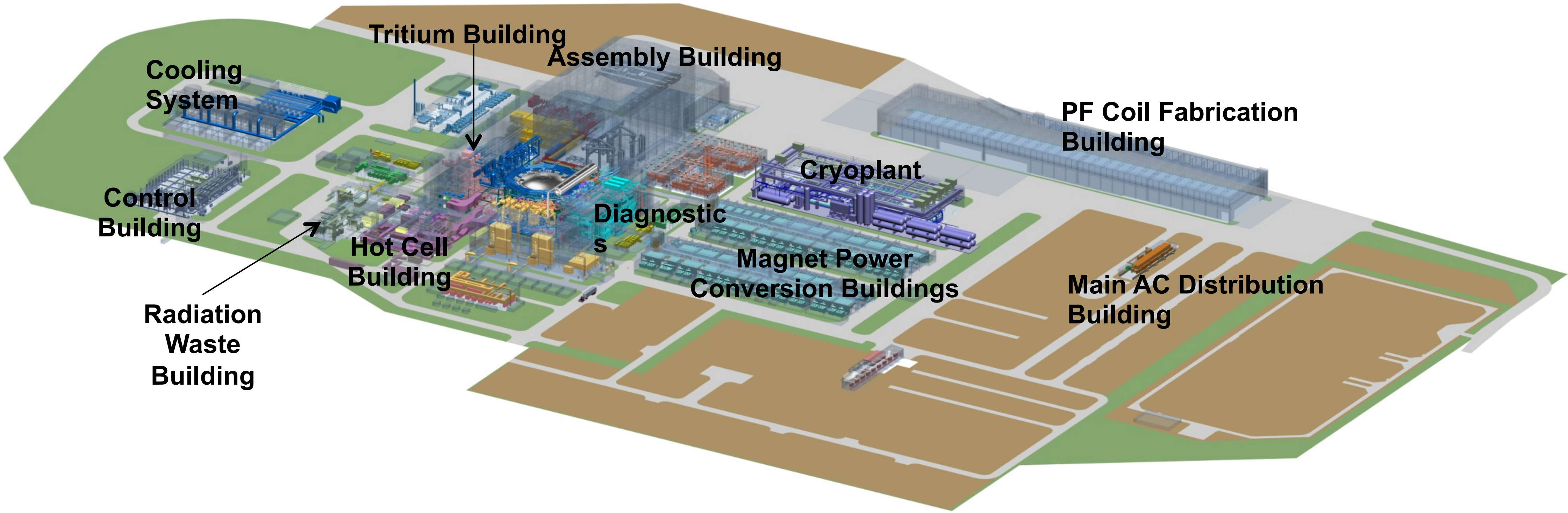
Service Vacuum System has ~ 1800 Clients

- Distribution box and client ganging simplify and reduce interface connections
- 1800 clients reduced 20X to 90 distribution boxes with standard pump and purge interfaces








Tritium Building
Assembly Building
Cooling System
PF Coil Fabrication Building
Cryoplant
Control Building
Diagnostics
Hot Cell Building
Magnet Power Conversion Buildings
Main AC Distribution Building
Radiation Waste Building